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RADIO PRINCIPLES

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RADIO PRINCIPLES

Prepared for

AIRCRAFT FLIGHT AND GROUND CREWS

By JOHN W. STONE

Art Direction by

WILLIAM DAMON

WASHINGTON

THE INFANTRY JOURNAL

1944

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C O N T E N T S

Page	Subject
1	Vacuum tubes
7	Amplification; Class A amplifiers
13	Class B and C amplifiers
21	Grid bias; vacuum tube oscillators
27	Crystal oscillators; neutralization; multi-element tubes
34	Multi-element tubes; plate tank circuits; doublers
42	RF circuit coupling and filters
50	RF load coupling
56	Aircraft transmitter output coupling
62	Antennas; keying; microphones; speech amplifiers
69	Modulation; plate modulation
77	Grid modulation; linear amplifiers
83	Frequency indicators
90	Frequency indicators
96	RF amplifiers; detection; AF amplifiers
105	Superheterodyne receivers
111	Transmission of radio waves
118	Static; fading; choice of frequencies
124	Direction finding equipment
130	Trouble shooting

IMPORTANT

This material was not prepared for home study. It was prepared for use by the student and instructor in the classroom.

Each line above represents one hour of lecture.

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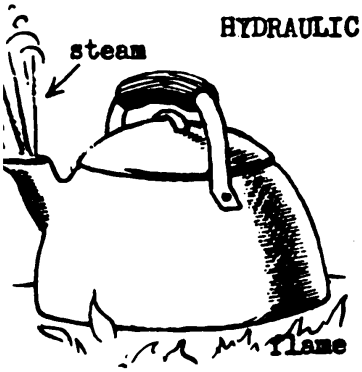
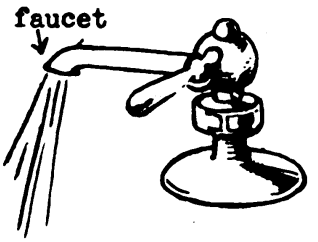
RADIO PRINCIPLES

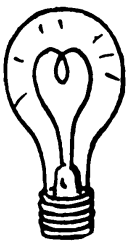
FILAMENTS OR CATHODES

HYDRAULIC





ELECTRIC



gives off
light and electrons

A heated teakettle gives off steam.

An open faucet permits water to flow.

Heated metal gives off particles of matter called "electrons". As temperature is increased, more electrons are given off.

Some metals must be heated to a higher temperature than others to produce the same amount of electrons.

A vacuum tube has a thin wire "filament" which is heated to produce electrons. Sometimes the filament is covered with a close fitting sleeve coated with an oxide which supplies electrons when heated by the filament.

The sleeve or filament is called a "cathode". It is enclosed in a glass bulb or a metal envelope from which the air is pumped so the hot filament will not burn up.

Source	Temperature	Remarks
Filament	Room temperature	Supplies hardly any electrons
Oxide coated sleeve	Red hot	A good source of electrons. Used widely for radio tubes
Filament	White hot	Also a good source of electrons.

EXAMPLE PROBLEM

1. Is the light we see from the filament an electron stream?

   ANS: No. Electrons are not visible.

CLASSROOM PROBLEMS

1. If a filament is heated beyond white heat, what will happen?

   ANS:_____

2. Is an increase of electron flow like increase of water flow?

   ANS:_____

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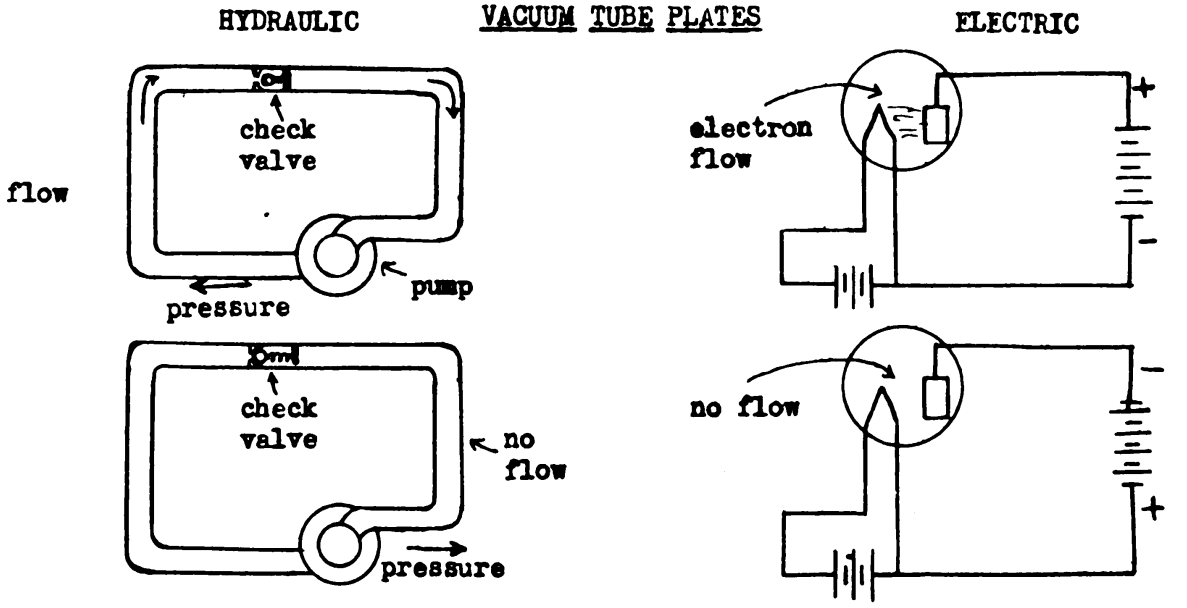
VACUUM TUBE PLATES



A check valve permits flow in only one direction.

When a metallic plate is placed near a vacuum tube filament, electrons will flow between the filament and plate if the plate is more positive than the filament.

The flow of electrons is actually an electric current. This means that the larger the flow, the less resistance the tube is offering to it.

When the plate is negative with respect to the filament, electrons will not flow to the plate. This means that the resistance is extremely high.

A vacuum tube having a filament and plate is called a "two element" tube or "diode"

EXAMPLE PROBLEMS

1. Does the space between plate and filament act like an ordinary resistor?

   ANS: Yes, for any given filament temperature and plate voltage (positive).

2. Vacuum tubes are constructed so the plate almost encloses the filament. Why?

   ANS: So a large part of the electrons from the filament will be able to reach the plate and will not be wasted by going elsewhere.

CLASSROOM PROBLEMS

1. A certain current is flowing between plate and cathode. A higher positive voltage is connected to the plate. What will happen?

   ANS:_____

2. A certain current is flowing between plate and cathode. If the filament temperature is raised, what effect will it have on the resistance between plate and cathode? What is the effect of decreasing plate-cathode spacing ?

   ANS:_____

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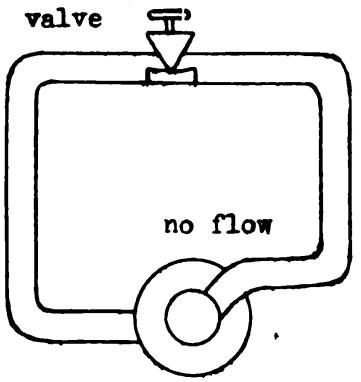
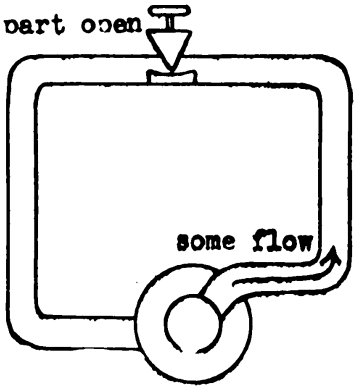
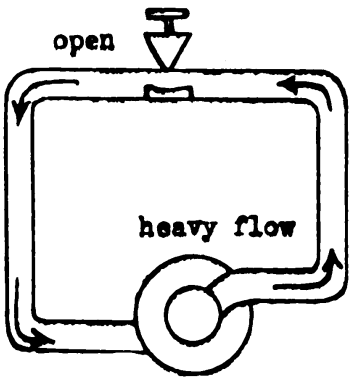
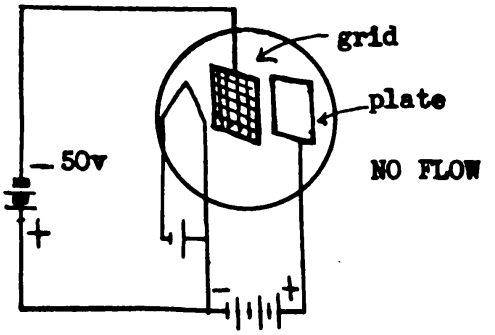


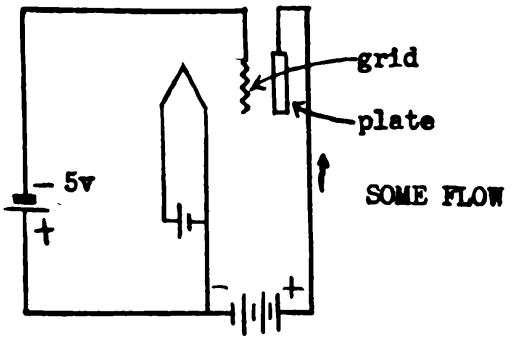


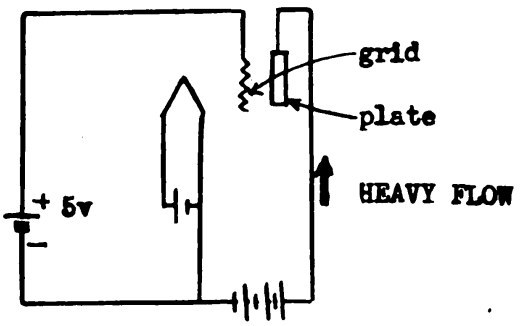


VACUUM TUBE GRIDS

ELECTRIC







A valve will regulate flow of water in a pipe.

A network of wires placed between the plate and filament of a vacuum tube will regulate the flow of electrons.

Such a network is called a "grid".

When the grid is negative with respect to the filament, it will hinder the flow of electrons to the plate. The effect is the same as adding resistance between the filament and plate.

As the grid is much less negative, it allows the flow of electrons to increase. The effect is the same as reducing resistance between the filament and plate.

When a high negative voltage is placed on the grid, the current between filament and plate is cut off entirely. Considerable negative voltage is required to do this, just as considerable force is required to completely shut off a faucet which has a tendency to drip.

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When a positive voltage is placed on the grid, the current between filament and plate becomes large. It is limited by the number of electrons the filament can supply. The current cannot increase indefinitely.

A tube having a filament, grid and plate is called a "three element" tube or "triode".

EXAMPLE PROBLEM

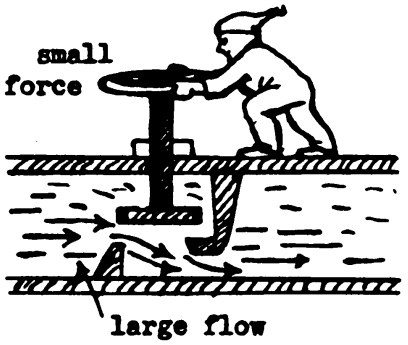
1. At any one grid voltage and plate voltage, can the tube be considered as a resistor?

   ANS: Yes. Providing the plate is more positive than the filament.

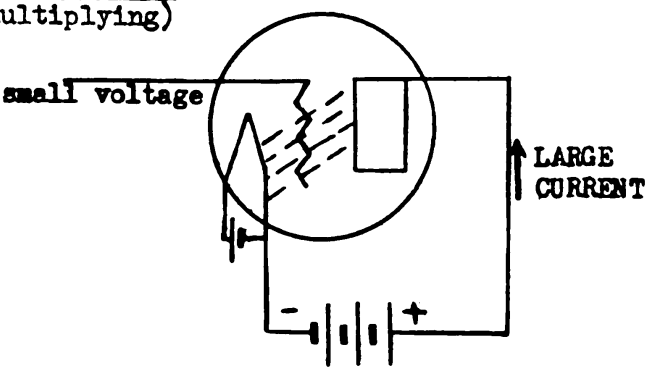
CLASSROOM PROBLEM

1. An alternating voltage is placed on the grid. How will the current through the tube vary?

   ANS: _____



POWER AMPLIFICATION
(Power multiplying)



A valve requires very little energy to control a large flow of water.

A vaccum tube grid requires almost no power to operate it. It can control a very large electric current which may operate some piece of equipment.

The closer the spacing between the grid wires, the easier is the control.

The tube itself does not supply power. It controls the power supplied by the battery connected to the plate.

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EXAMPLE PROBLEMS

1. Why is any power required to operate a grid when it is negative?

   ANS: A very small current may flow in the grid circuit. It is almost too small to measure. For practical purposes the power is zero.

2. If grid wires are far apart, they have less control over the plate current flow. Why use wide spacing at all?

   ANS: Although the close wires will give easy control, they will interfere with maximum current flow. Widely spaced wires will allow a greater maximum current to flow. Both types of spacing are used.

CLASSROOM PROBLEMS

1. If the grid were made highly positive, what do you think would happen?

   ANS:_____

2. Is any grid power necessary when the grid is positive?

   ANS:_____

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HOMEWORK

1. The filaments or cathodes of small receiving tubes are usually coated with an oxide. The filaments of transmitting tubes usually have an oxide mixed with the tungsten in the filament. Why would you expect the cathodes or filaments of such tubes to be operated at much lower temperatures than pure tungsten filaments?

   ANS:_____

2. Why is it important to maintain the correct voltage on vacuum tube filaments?

   ANS:_____

3. What is the effect on the resistance between plate and cathode of a diode when plate-cathode spacing is increased?

   ANS:_____

4. The electron producing ability of a cathode is rapidly destroyed when it is forced to deliver an overload of current (electrons at a faster rate than it was designed to produce). What precaution should be observed regarding the average plate current of a tube?

   ANS:_____

5. A vacuum tube may be used as a relay to control current flow. What grid voltage would you use to stop the current flow? To cause current to flow? Between which elements of the tube would this flow occur?

   ANS:_____

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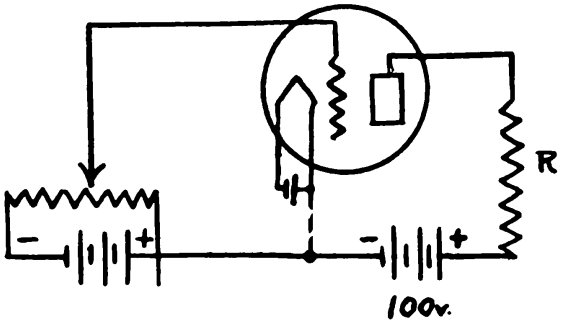
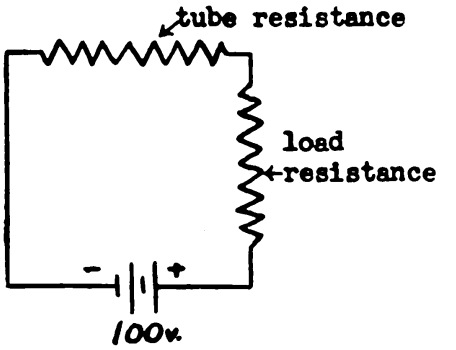
RADIO PRINCIPLES

POWER FROM A TUBE





A tube is equivalent to a resistor. The tube shown above (with a resistor load) can be shown in the simple circuit at the right.

This is true at one grid voltage. The value of tube resistance will differ for each specific value of grid voltage.

Since a tube acts as a resistor, power will be dissipated when current flows through the tube.

The "efficiency" of a tube is the ratio of the power delivered to the load resistance compared to the total power drawn from the plate battery.

EXAMPLE PROBLEMS

1. The tube resistance is 1,000 ohms and the load is 1,000 ohms. How much votage will be present across the tube and how much across the load?

   ANS: The voltage will divide equally. There will be 50 volts across each.

2. Where does the power come from to heat the resistors?

   ANS: From the plate battery.

3. A tube draws 100 watts from the plate battery. 50 watts are delivered to the load. What is the efficiency?

   ANS: Efficiency = $\frac{\text{power to load}}{\text{total power drawn}} = \frac{50}{100} = .50$ or 50%

CLASSROOM PROBLEMS

1. Suppose the two resistors above had a value of 5,000 ohms each. The battery voltage is 100 v. How much power (in watts) will be lost in heat in the resistor? How much in the tube?

   ANS:_____

2. The resistance of a tube is 1000 ohms. Which load will receive the greatest amount of power (1) a short-circuit, (2) 1,000 ohms? Why?

   ANS:_____

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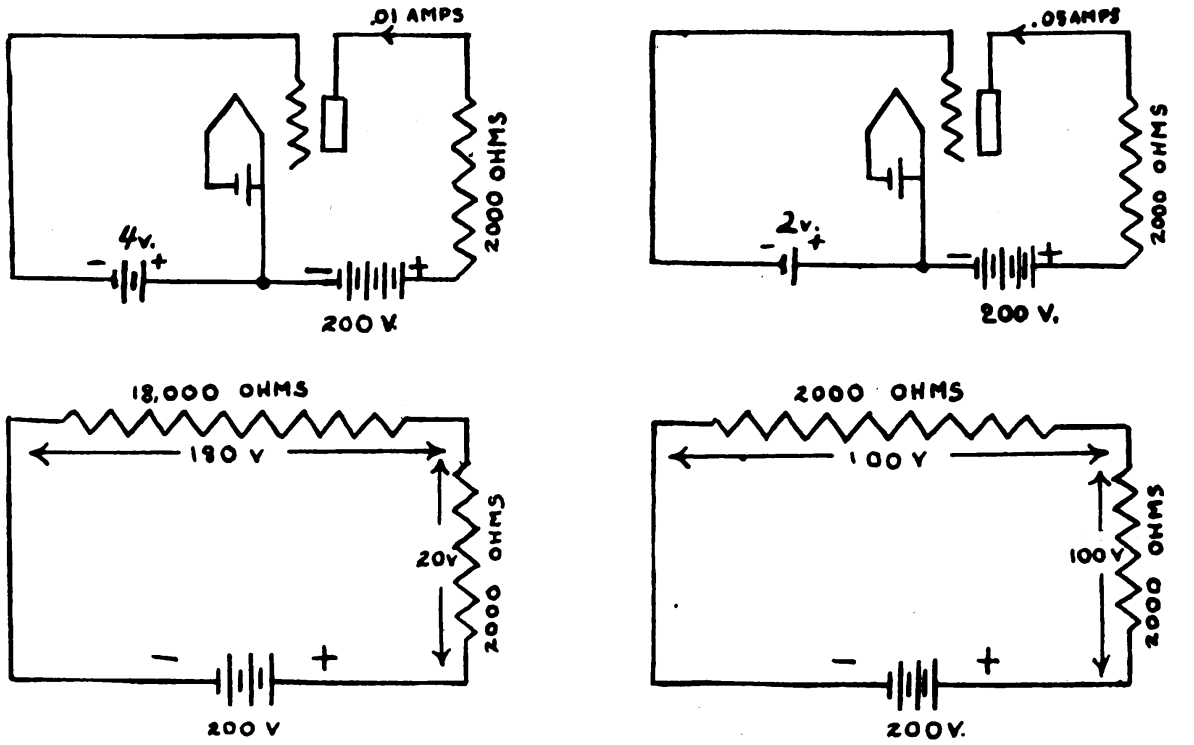
VOLTAGE AMPLIFICATION
(Voltage multiplication)



The tube at the left has .01 amperes flowing through it under the conditions shown. The voltage drop across the load resistor is then 20 volts (.01 x 2000). Thus 180 volts must exist across the tube. Its resistance is then 18,000 ohms.

The tube at the right shows the conditions when the grid voltage is raised to -2 volts. The tube resistance is now but 2,000 ohms.

A change of two volts at the grid gives a change of 100 - 20 = 80 volts on the load. Thus it has an amplification of 40 times in this circuit.

EXAMPLE PROBLEMS

1. Suppose the current through the tube has only risen to .02 amperes when the grid changed two volts. What is the amplification now?

   ANS: The drop across the load resistor is now:

   .02 x 2,000 = 40 volts

   Two volts grid change gives 40 - 20 = 20 volts at load

   Two volts grid change gives 20 volts load change

   One volt gives ten, so the amplification is ten times

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2. The load resistors in the diagrams shown were lowered to 200 ohms. What is the amplification now if the grid voltage and plate current remain the same as shown?

ANS: Voltage across load in left hand case: .01 x 200 = 2 volts

Voltage across load in right hand case: .05 x 200 = 10 volts

Change in load voltage: 10 - 2 = 8 volts for a 2 volt change in grid voltage

A one volt grid change would give 4 volts load change, so the amplification is now four times.

CLASSROOM PROBLEMS

1. Does the amplification of a tube in a circuit vary with the size of the load resistor?

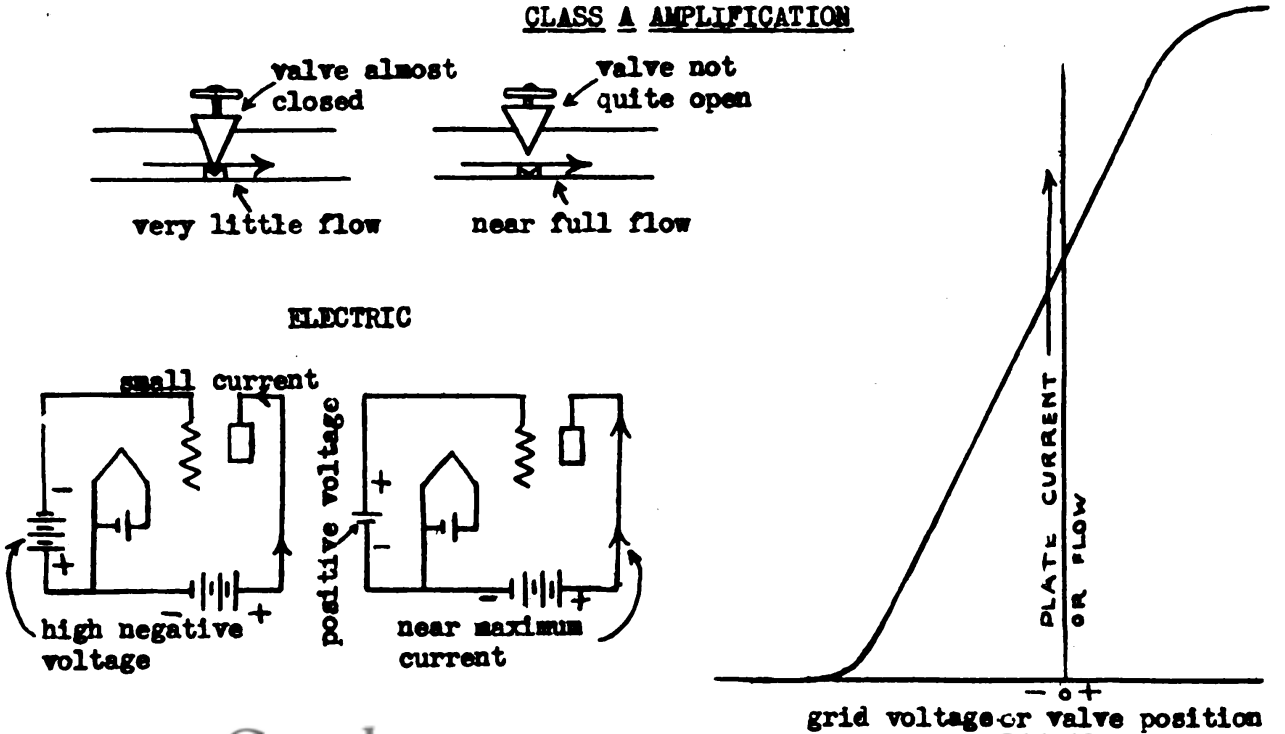
ANS: _____

2. A tube in a circuit showed 190 volts across the load with zero grid voltage. It showed 10 volts across the load with -100 volts on the grid. What was the amplification of the tube in this circuit?

ANS: _____

3. Does the change in load voltage divided by the change in grid voltage give the power or voltage amplification of the tube in a given circuit?

ANS: _____



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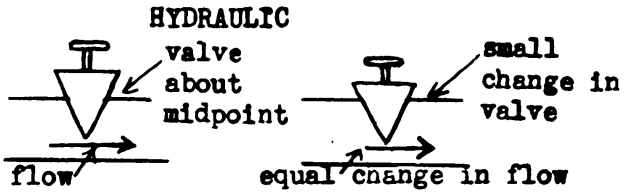
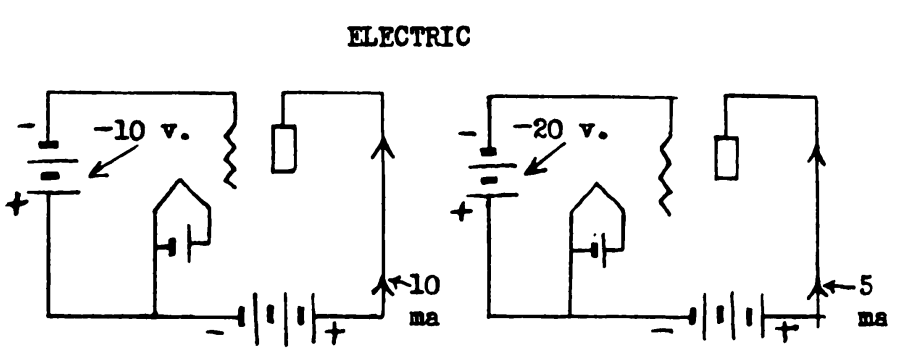
When the valve is almost closed, considerable force must be applied to cut off the flow of water entirely.

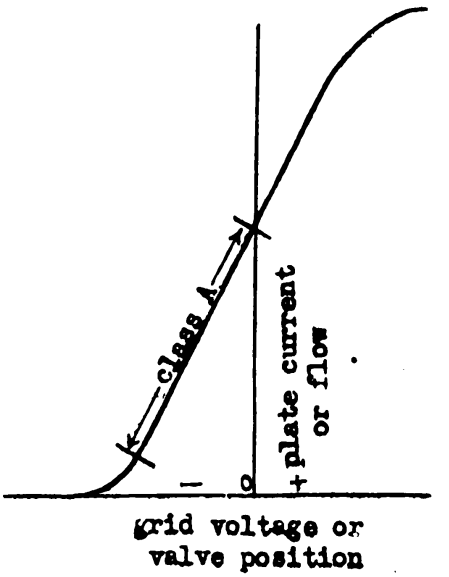
When the valve is 90% open, almost all the water flows which the pump will supply. Further opening of the valve adds little to the flow.

In a vacuum tube, when grid voltage is enough to almost cut off the flow of plate current, somewnat greater negative voltage must be used to completely stop it.

When grid voltage is positive, a heavy plate current will flow. Further increasing grid voltage will not add much to this current. Few more electrons are available from the filament. In addition, some electrons are being used to cause current to flow through the grid.



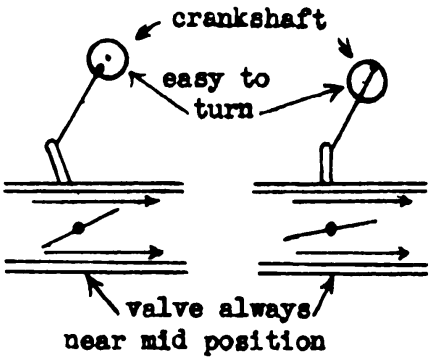


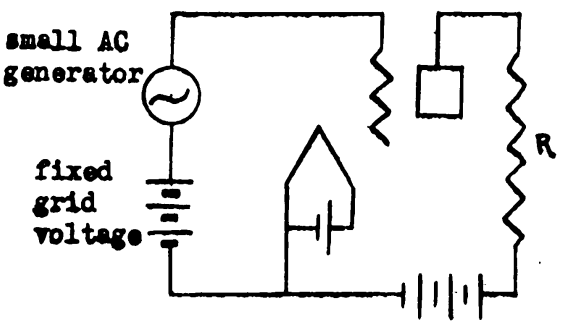


At midpoint valve position, any change in valve setting produces an equivalent change in the flow.

At grid voltages about midway between the points for zero and maximum plate current, any change in the grid voltage produces an equivalent change in plate current.

The "Class A" amplifier operates with grid voltages in this range.





A valve near mid-position is easy to turn. Only a small amount of power is required to rock the valve back and forth. Rocking the valve back and forth will produce corresponding changes in the flow through it.

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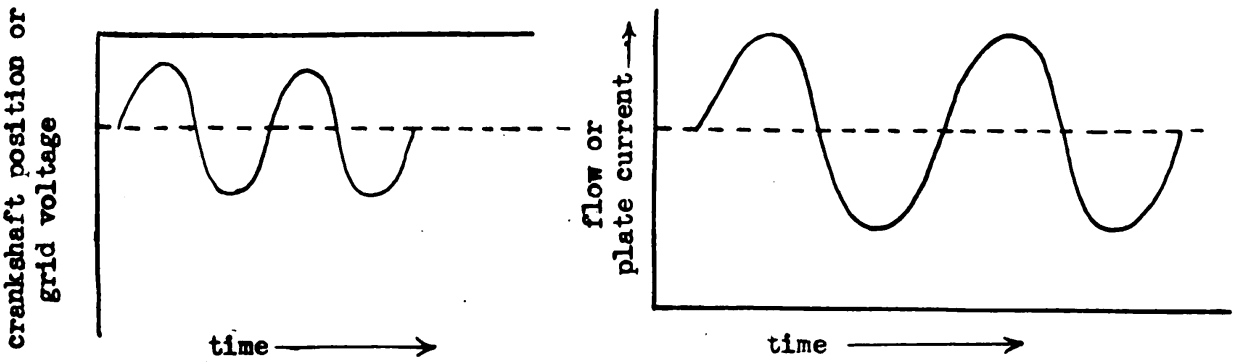
When the fixed voltage (bias) on the grid allows some plate current to flow, a small AC generator connected in series will cause variations in the plate current.



The plate current of a Class A amplifier varies exactly as the grid voltage is varied. Plate current flows at all times. It is varied upward and downward in accordance with the AC voltage source connected to the grid.

Tube efficiency is usually about 30%.

COMMON USES

Class A amplifiers make faithful voltage amplifiers because grid voltage changes are followed accurately by plate current changes.

Since efficiency is low, Class A amplifiers are seldom used where power of more than a few watts is required in the plate load.

They are used to amplify at radio frequencies (high frequencies) in radio receivers and to amplify at audio frequencies (voice frequencies) in both receivers and radiotelephone transmitters.

EXAMPLE PROBLEM

1. When only a small amount of power is available, why is it desirable to use a Class A type amplifier?

   ANS: Because it requires virtually no grid driving power to produce amplification.

CLASSROOM PROBLEM

1. It is desired to produce a large voltage amplification. Should the load resistor have a low or a high resistance as compared to the tube resistance? Why?

   ANS:_____

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HOMEWORK

1. The grid voltage of a tube is adjusted so the tube resistance is 2,000 ohms. A plate battery of 100 volts is used. What value of load resistance will draw the greatest amount of power from the tube? What will be the plate efficiency of the tube?

   ANS:_____

2. How much power will be delivered to the load resistor in Question 1?

   ANS:_____

3. A 10,000 ohm load resistor is connected to the plate of a vacuum tube. A plate battery of 1,000 volts is used. When grid voltage is -100 volts, plate current is 10 ma. What is the voltage across the tube? Across the load?

   ANS:_____

4. The grid voltage of the tube in Question 3 is changed to -50 volts. Plate current increases to 30 ma. What is the voltage across the tube? Across the load?

   ANS:_____

5. What voltage amplification is produced by the tube in Questions 3 and 4?

   ANS:_____

6. What is the resistance of the tube in Question 3? In Question 4?

   ANS:_____

7. A DC milliammeter is connected in series with the plate battery of a Class A amplifier tube. The DC meter will continue to read a steady plate current when an AC voltage is applied to the grid. Why?

   ANS:_____

8. Why will no grid current be drawn by a properly adjusted Class A amplifier?

   ANS:_____

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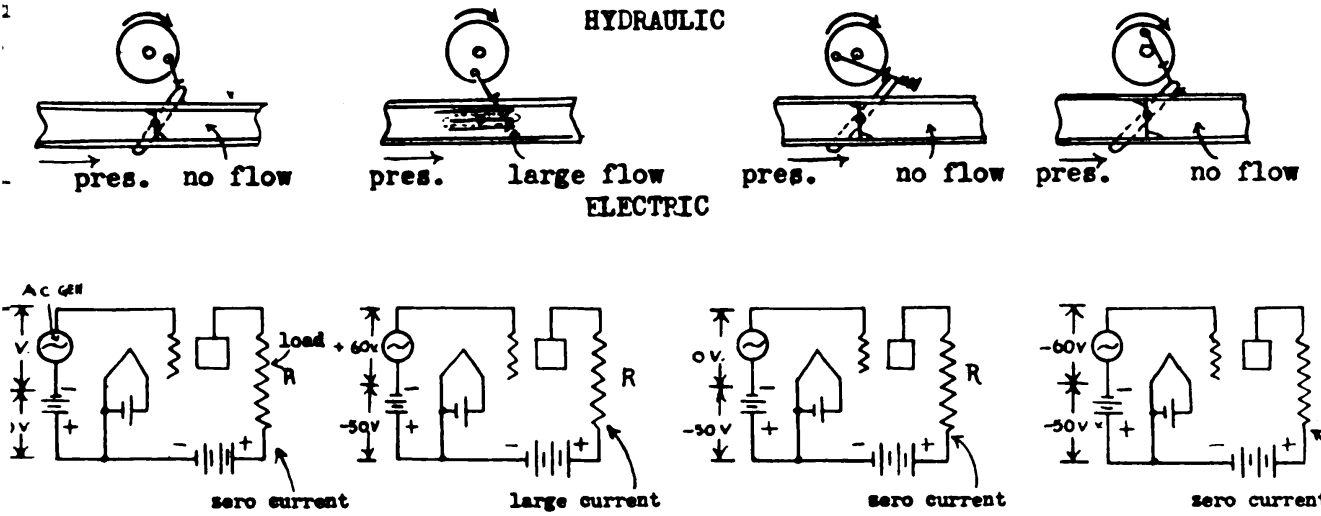
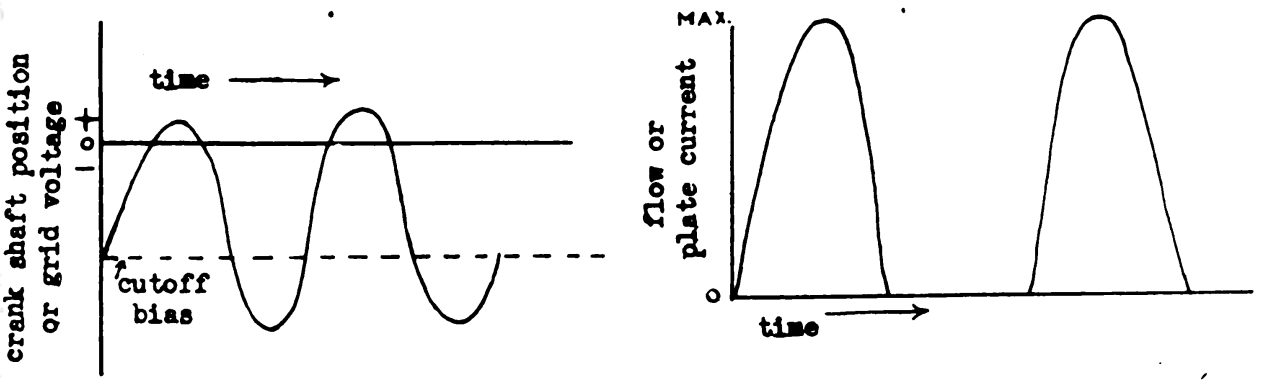
CLASS B AMPLIFICATION



As the valve driving wheel rotates, the valve is opened completely and then closed during the first half revolution. During the second half revolution, the valve remains closed. More force is required than to just rock the valve back and forth.

The fixed bias on the vacuum tube is adjusted to <u>just about</u> cut-off plate current flow. The AC generator connected in series with it has a peak voltage sufficient to cause large plate current to flow during the positive halves of the cycle. No plate current flows during the negative halves of the cycle, since the total grid voltage is then even more negative than required to cut off plate current.

This is called a "Class B" amplifier. More driving voltage and fixed grid bias are required than for a Class A amplifier.



The positive halves of the driving voltage cycle are reproduced exactly by large increase in plate current. Plate current is zero during the negative halves of the cycle. Grid current usually flows during part of the positive grid voltage peak. Thus actual power is required for driving the tube (about 1/50 as much as the tube delivers).

Tube efficiency is about 60% maximum.

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COMMON USES

Class B amplifiers are used as power amplifiers for both radio frequency ("RF") and audio frequency ("AF") power.

Their higher efficiency often makes them preferable to Class A amplifiers when sufficient driving power is available for Class B operation.

EXAMPLE PROBLEM

1. What is the effect on the output of a Class B amplifier if too much driving voltage is used?

   ANS: The positive peaks of the driving voltage will raise the total grid voltage so high that the plate current will reach the maximum value the tube will pass. If even more driving voltage is used, the plate current will not be able to follow it at the peaks. The output waves will have flat tops. This is called distortion.

CLASSROOM PROBLEM

1. What is the effect if the bias on a Class B amplifier is set at a higher negative voltage than is required to cut off plate current?

   ANS:_____

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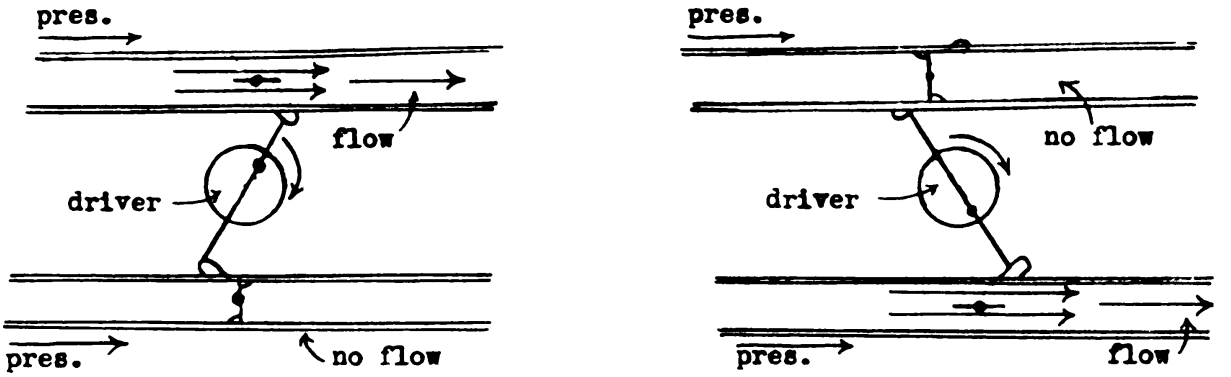
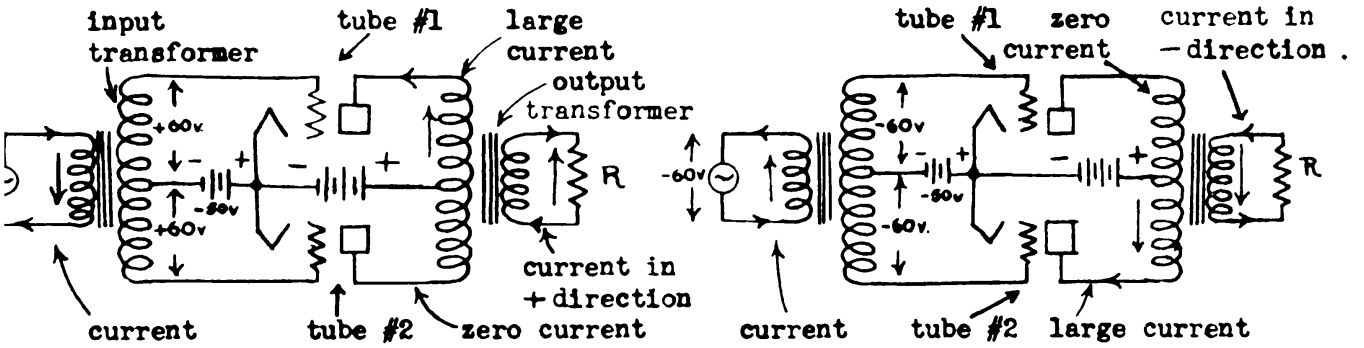
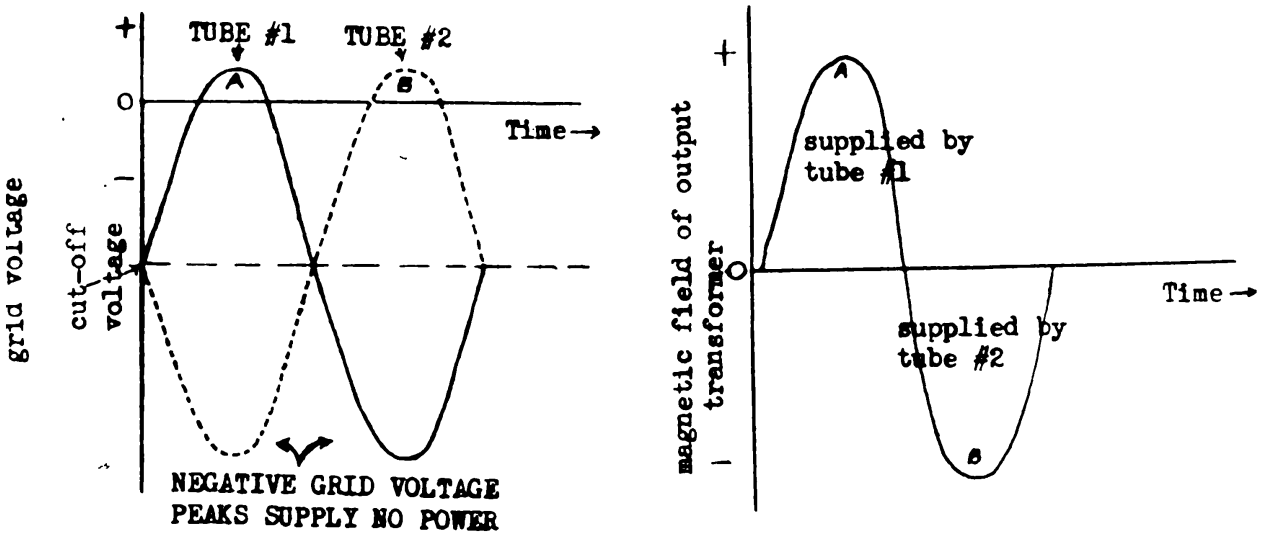
PUSH-PULL AMPLIFICATION

HYDRAULIC



ELECTRIC





The two valves are connected by a lever so that when one is closed the other is open and vice versa.

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Two vacuum tubes can be connected so that when plate current is flowing through one, the other is not operating and vice versa.

This is called a "push-pull" connection.

Each tube passes plate current only half the time.

The current through the load exactly follows the alternations of the driving voltage supplied by the AC generator.

COMMON USES

Class B push-pull connection is always used when amplifying power at audio (voice) frequencies. Otherwise, severe distortion would result because of the elimination of half of each cycle from the output.

Push-pull connection is sometimes used when amplifying power in radio (high) frequencies.

EXAMPLE PROBLEM

1. Why is no filament battery shown in the diagram?

   ANS: The connections to the filament battery or transformer are often left off of circuit diagrams to simplify them. It is always understood that a suitable source of power will be supplied to heat the filaments.

CLASSROOM PROBLEMS

1. What will be the effect on the output to the load if the center connection ("center tap") on one of the transformer windings is not in the exact center of the winding?

   ANS:_____

2. What will be the effect in a Class B push-pull amplifier if one of the tube filaments burns out?

   ANS:_____

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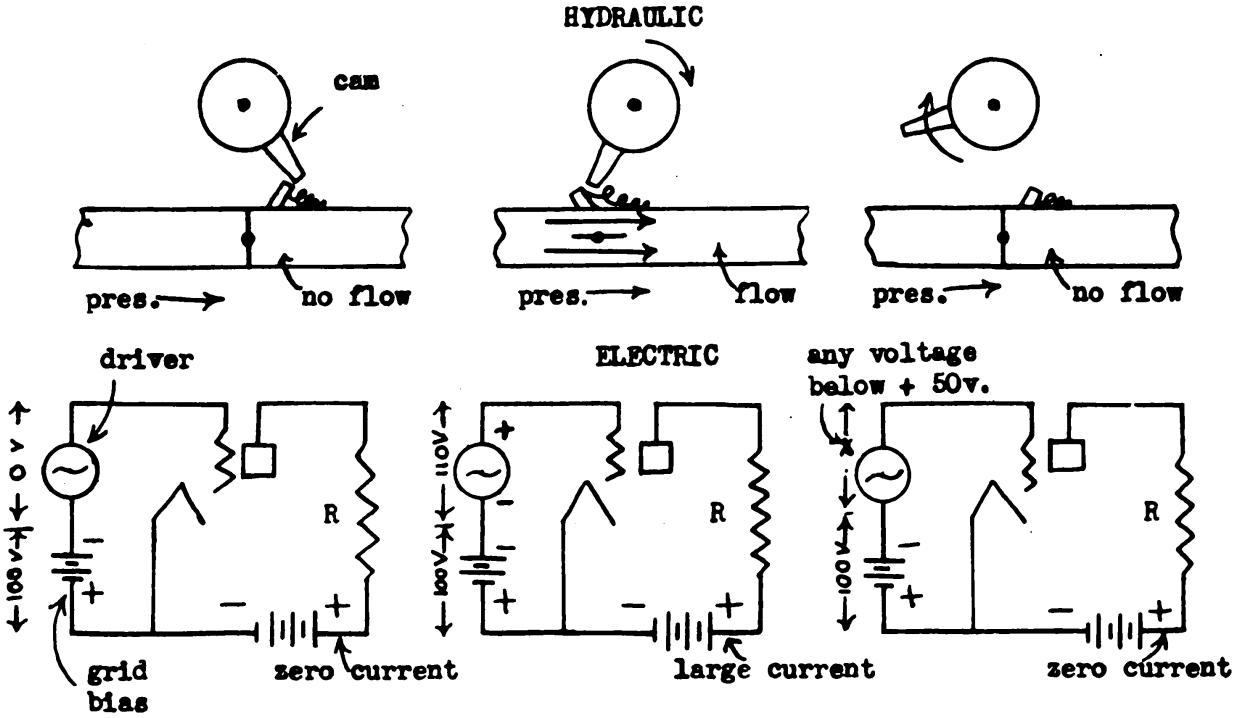
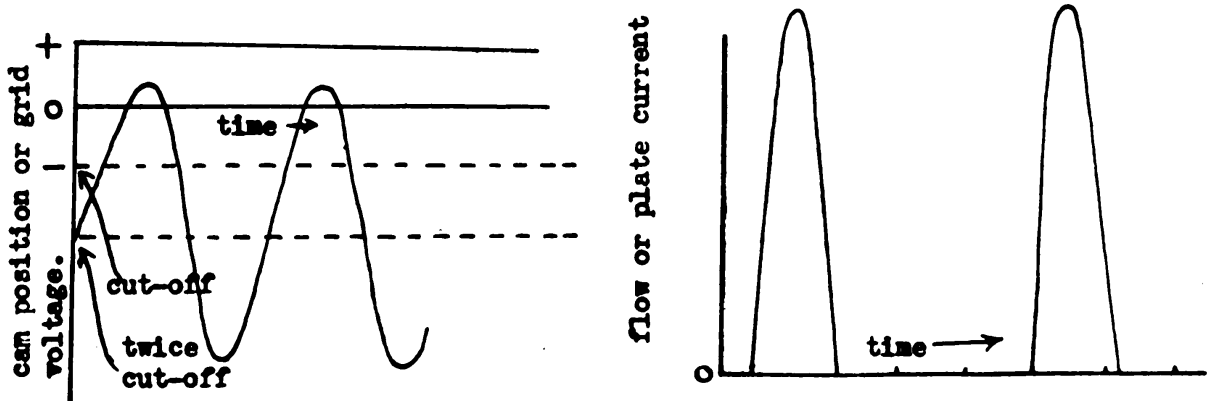
CLASS C AMPLIFICATION



The valve is open for only a short time during a revolution of the cam. Flow reaches its maximum very quickly and is then cut off during the remainder of the revolution. Considerable force will be required to turn the cam so as to operate the valve rapidly.

The grid bias voltage is adjusted to a negative value at least twice as great as required for cut-off of plate current. In this example, cut-off voltage is -50 volts. Bias voltage is set at -100 volts. Plate current will only flow when generator voltage is higher than +50 volts. More driving power is required than for a Class B amplifier.

This is called a "Class C" amplifier.



The plate current is zero except during the positive peaks of driver voltage. Part of the positive driving voltage cycle does not appear in the output since it is used in overcoming the high negative grid bias. Tube efficiency may be as high as 80%.

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COMMON USES

Class C amplifiers are used as power amplifiers for radio frequency power.

Class C amplifiers are never used for audio frequency amplification, since part of the positive cycle as well as all of the negative cycle does not appear in the out put. Distortion would be bad and render the amplifier useless.

EXAMPLE PROBLEMS

1. What is a simple way to insure having sufficient grid bias for Class C operation?

   ANS: Adjust the negative grid bias to a value which cuts off the plate current. Then add at least the same amount of additional negative bias.

2. Is more driving power required when negative bias is three times cut-off value?

   ANS: Yes. This is like opening and closing the valve even more rapidly. More power is required.

CLASSROOM PROBLEMS

1. What will be the effect on the output if the amount of negative bias is increased without increasing the amount of driver voltage?

   ANS:_____

2. If the amount of negative bias is increased, what change must be made in the amount of driver voltage to maintain high peaks in plate current?

   ANS:_____

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COMPARISON OF CLASS A, B AND C AMPLIFICATION

Characteristic	Class A	Class B	Class C
Negative grid bias required	Small negative	About cut off	Twice cut off or more
Grid driving power required	Very small	About 2% of output power	About 10% of output power
Grid current flow	Practically none	On positive grid voltage peaks	On positive grid voltage peaks
No-signal plate current	Plate current flows at all times	Near zero	Zero
Plate current during positive half of grid drive	Increases with grid voltage	Increases with voltage	Current on grid voltage peak only
Plate current during negative half of grid drive	Decreases with grid voltage	Zero	Zero
Use as voltage amplifier	Widely used	Never used	Never used
Use as power amplifier	Only on low power	Frequently used	Frequently used
Use as audio frequency amplifier	Widely used	Used as push-pull power amplifier	Never used
Use as radio frequency amplifier	Occasionally for very low power	Frequently used	Frequently used
Use as push-pull amplifier	Frequently used	Frequently used	Sometimes used
Tube efficiency	30% or less	60% or less	80% or less

EXAMPLE PROBLEM

1. Why are Class B and C amplifiers <u>not</u> very useful as voltage amplifiers?

   ANS: Because they require considerable grid driving voltage and do not give as much voltage gain as a Class A amplifier.

CLASSROOM PROBLEM

1. Why are class B audio amplifiers always used in push-pull?

   ANS: _____

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HOMEWORK

1. Why is power required to drive the grid of a Class B amplifier tube?

   ANS:_____

2. The grid bias of a Class B amplifier is changed to an amount which allows considerable plate current to flow. Is the operation still Class B or does it more closely resemble Class A?

   ANS:_____

3. Why is it undesirable to attempt to operate a tube as a Class C amplifier when very little grid driving power is available?

   ANS:_____

4. Why are Class C amplifiers <u>never</u> used for audio frequency amplification?

   ANS:_____

5. Why does the plate efficiency of a Class C amplifier increase when more negative grid bias is used?

   ANS:_____

6. Why is more grid driving voltage required when more negative grid bias is used on a Class C amplifier?

   ANS:_____

7. A DC milliammeter is connected in series with the plate battery of a Class B or C amplifier tube. The reading of the DC meter will decrease as the amount of grid driving voltage is decreased. Why?

   ANS:_____

8. If the grid driving voltage in Question 8 is increased beyond a certain point, the DC plate milliammeter will no longer show an increase. Why?

   ANS:_____

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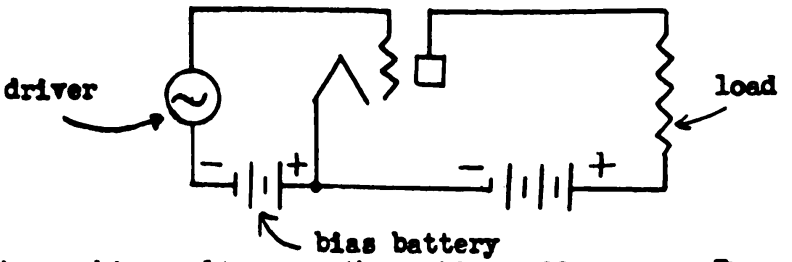
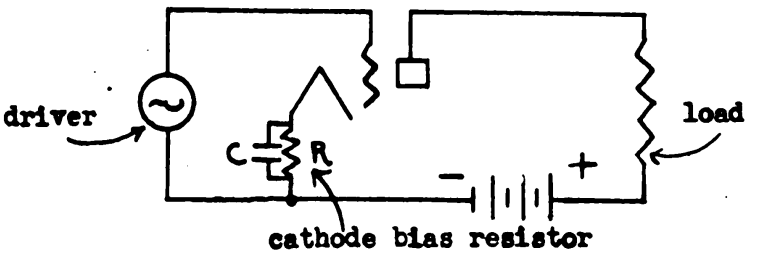
VACUUM TUBE GRID BIAS SUPPLY



Battery bias keeps bias voltage on the grid at all times. This voltage is varied upward and downward by the AC from the driver.

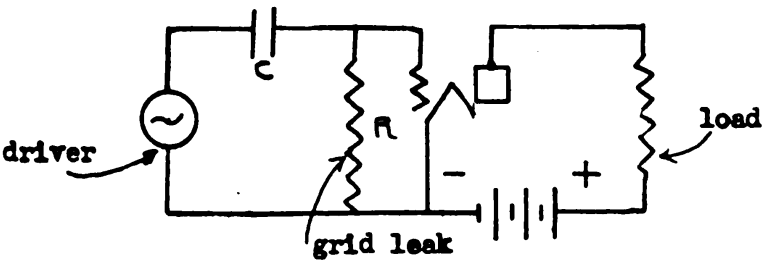
Battery bias is often undesirable. It requires additional batteries to supply the bias voltage. If grid current flows, it goes through the battery in the wrong direction, making battery life short.



Bias can be obtained by connecting a resistor in series with the cathode. The DC plate current flows through this resistor. This causes a voltage across the resistor. The cathode is made positive with respect to the grid, which is the same as the grid being negative with respect to the cathode.

This is called "cathode bias". A condenser is connected across the resistor. When the plate current is varied, the AC part of the plate current goes through this condenser to the filament. This condenser keeps the bias steady.

Cut-off cannot be obtained with cathode bias. Some plate current must flow to produce bias.



Bias can be obtained by connecting a resistor between the grid and cathode. During the positive halves of the driver voltage cycle, the grid will be positive and grid current will flow. This current, flowing through the resistor, causes voltage across the resistor and places grid bias on the tube.

The resistor used is called a "grid leak". Hence, this is "grid leak" bias. The condenser in series with the driver prevents short-circuiting the bias voltage through the driver. It does not hinder the passage of AC current from the driver. The condenser maintains steady bias voltage. It stores voltage during negative half cycles of driver voltage.

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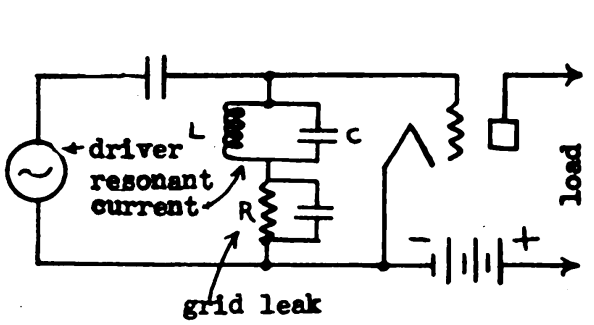

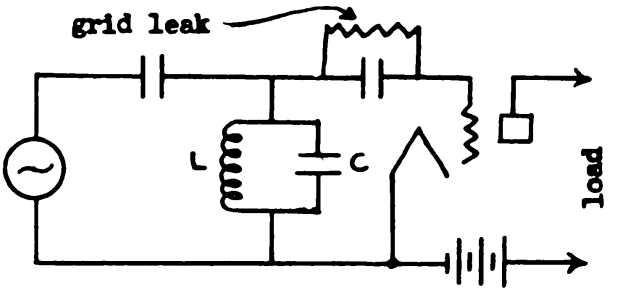

Often it is desired to amplify power at only one particular frequency. The inductor L and condenser C are proportioned to be resonant at this frequency. This makes the impedance very high across the parallel resonant circuit at the desired frequency. The grid voltage is thus very high at this frequency and much lower at any other.

A condenser is connected across the grid leak, since there would be loss of power if the AC were forced to travel through the resistor.

In the circuit at the right, the grid leak and condenser have been moved, but the operation is still the same. The condenser maintains steady bias voltage.

The use of a grid leak to obtain bias always requires that the grid be driven positive and that grid current flows. Thus it cannot be used for class A.

EXAMPLE PROBLEMS

1. A tube is to be operated with driving voltage turned on and off intermittently. What type of bias should be used?

   ANS: Battery or cathode bias should be used. Either of these would limit the plate current to reasonable values during times there was no driving voltage.

2. Why would grid leak bias be undesirable if driving voltage is intermittent?

   ANS: During times there is no driving voltage, the grid is at zero voltage. Consequently, the plate current might rise to such values as to seriously injure the tube.

CLASSROOM PROBLEMS

1. Plate current of 100 ma. flows through a 500 ohm cathode bias resistor. How much bias is developed?

   ANS: _____

2. D.C. grid current of 10 ma. flows through a 5,000 ohm grid leak. How much bias is developed?

   ANS: _____

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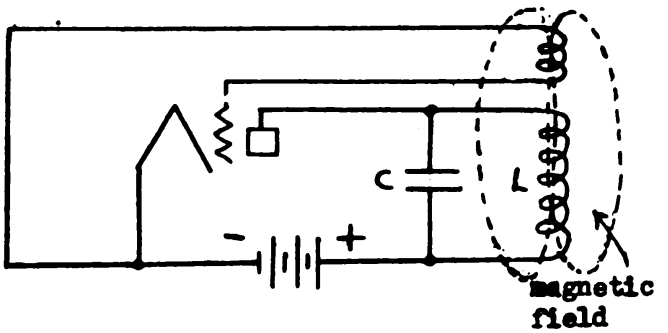
3. For a given amount of bias on a tube, which would have the highest resistance; a grid leak or a cathode bias resistor? Why?

ANS:_____

VACUUM TUBE OSCILLATORS



Step	Cause	Effect	Result
1	Turn on filament	Plate current increases	Field increases
2	Field increases	Grid voltage increases in positive direction	Plate current reaches maximum
3	Plate current reaches maximum	Field becomes steady	Grid voltage drops to zero
4	Grid voltage drops to zero	Plate current decreases	Field decreases
5	Field decreases	Grid voltage becomes negative	Plate current becomes zero
6	Plate current becomes zero	Field becomes zero	Grid voltage becomes zero
7	Grid voltage becomes zero	Plate current increases	Field increases
8	Same as step 2.		

The cycle will be repated over and over as long as the tube is turned on.

Condenser C and inductor L, connected in series with the plate circuit, govern the rate at which plate current is allowed to increase and decrease.

The oscillations will be at the resonant frequency of the condenser and inductor.

An inductor and condenser (having a resonant frequency) is called a "tuned circuit".

A vacuum tube with associated tuned circuits producing its own grid drive (excitation) is called a "self-excited oscillator".

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This circuit is the basis of vacuum tube oscillator circuits. The process of transferring energy from the plate back into the grid circuit is called "feedback".

Some vacuum tube oscillators use mechanical devices to maintain frequency. These operate on the same principle but are not spoken of as "self-excited".

EXAMPLE PROBLEMS

1. What is the effect of moving the grid coil away from the plate coil?

   ANS: The magnetic field set up about the plate inductor will not set up much voltage in the grid coil. The oscillations will become weaker and will disappear entirely when the grid coil is no longer in the field of the plat inductor.

2 The grid of an oscillator tube is supplied with sufficient bias to cut off the plate current. Will oscillation start when the tube is turned on?

   ANS: No. Oscillation cannot start because the plate current will remain at zero. However, if oscillation is once started, grid bias could be increased to a considerable negative value because of the voltage which would be obtained from the plate circuit.

CLASSROOM PROBLEMS

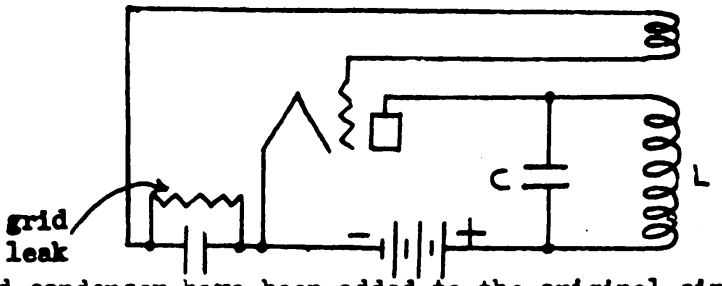
1 A variable condenser is used in the parallel resonant plate circuit. Will changing the capacity of the condenser change the frequency of oscillation?

   ANS:_____

2. A variable inductor is used in the parallel resonant plate circuit. Will changing the inductance of the inductor change the frequency of oscillation?

   ANS:_____

OSCILLATOR CIRCUITS



A grid leak and condenser have been added to the original circuit. The grid leak supplies bias. This limits the maximum peaks of the plate and grid current to values which will not damage the tube.

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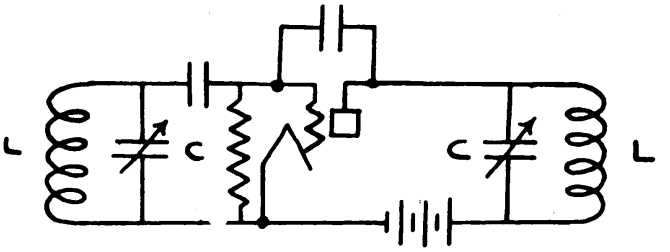
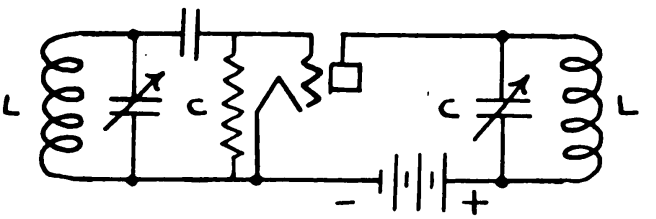


The plate current of an oscillator tube contains alternating current. The grid coil can be omitted and a condenser used to transfer energy from the plate to the grid circuit.

Energy transfer is produced by the alternating voltage across the condenser in the tuned plate circuit rather than by the changing field of the inductor.

Variable condensers are generally used in the tuned circuits so the resonant frequencies may be easily varied.

Oscillation will be strongest when plate and grid tuned circuits have the same resonant frequency. If their resonant frequencies are far apart, the grid and plate voltage will not change at the same rate. Oscillation will be weak or entirely absent.



Many vacuum tubes have sufficient capacity between the grid and plate to enable them to oscillate without the connection of an external condenser. The grid wires are close to the plate and give the same effect as a small condenser.

This is called a "tuned plate-tuned grid" oscillator.

EXAMPLE PROBLEM

1. Why are the oscillators shown with grid leak bias rather than battery bias?

   ANS: A large amount of negative battery bias would prevent oscillations from starting at all. Grid leak bias is desirable for easy starting of oscillations and also for simplicity.

CLASSROOM PROBLEM

1. A tube with rather small capacity between grid and plate will oscillate easily at high frequencies in a tuned plate-tuned grid circuit. Explain why an external condenser would probably have to be added between grid and plate if it is to be used as a low frequency oscillator.

   ANS:_____

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HOMEWORK

1. Cathode bias reduces effective plate voltage by the amount of cathode bias which is developed. Why?

   ANS:_____

2. It is often advantageous to use only sufficient cathode bias to limit plate current to a safe value with no excitation and obtain the remainder of the bias from a grid leak. Why?

   ANS:_____

3. Fixed bias of 50 volts is used on a tube. DC grid current with excitation is 50 ma. What is the bias with excitation? Without excitation?

   ANS:_____

4. A 5,000 ohm grid leak is connected to the tube in Question 3. DC grid current with excitation is still 50 ma. What is the bias with excitation? Without excitation?

   ANS:_____

5. The plate current of an oscillator tube becomes high if the tube stops oscillating. Why?

   ANS:_____

6. How could you probably tell by a DC plate current milliammeter whether or not a tube was oscillating?

   ANS:_____

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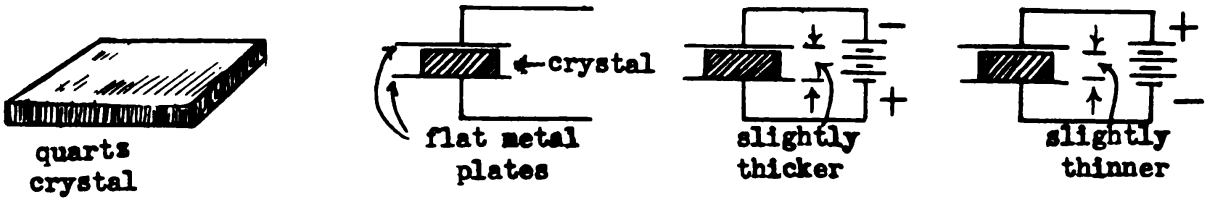
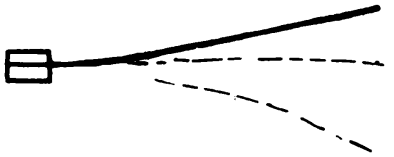
CRYSTAL OSCILLATORS

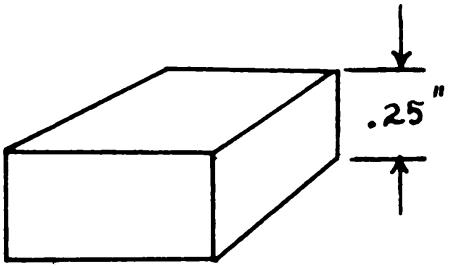


A correctly cut piece of quartz crystal has the peculiar property of becoming slightly thicker when voltage is placed across it in one direction and slightly thinner when voltage is placed across it in the other direction.

When an AC voltage is placed across the crystal, it will actually vibrate. Each crystal has a certain natural frequency of vibration which depends on the thickness of the crystal and the manner in which it was cut from the original large block of quartz. When AC voltage of this frequency is placed across the crystal, it will vibrate very strongly.

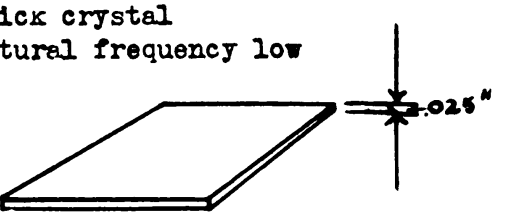


long spring vibrates slowly



thick crystal
natural frequency low

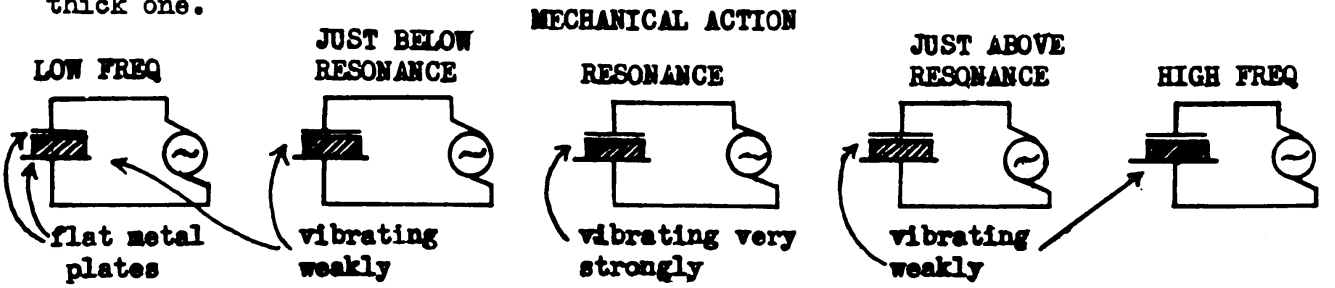
short spring vibrates fast



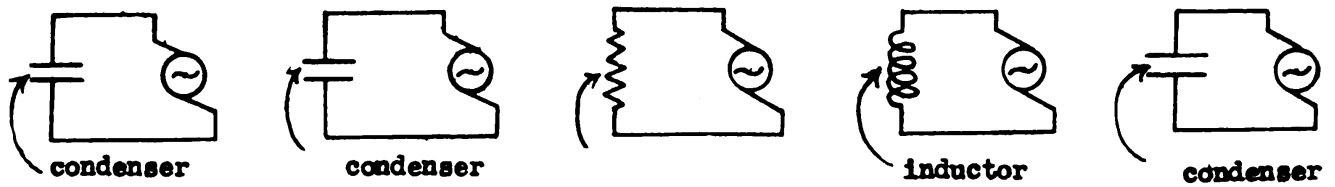
thin crystal
natural frequency high

A thin crystal has a higher natural frequency of vibration than a thick one.

MECHANICAL ACTION



ELECTRICAL EFFECT ON CIRCUIT



Quartz is an insulator. A quartz crystal placed between two metal plates

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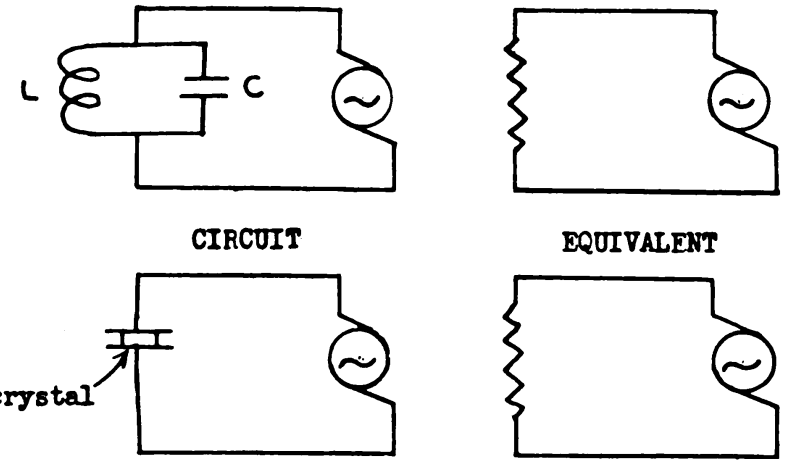
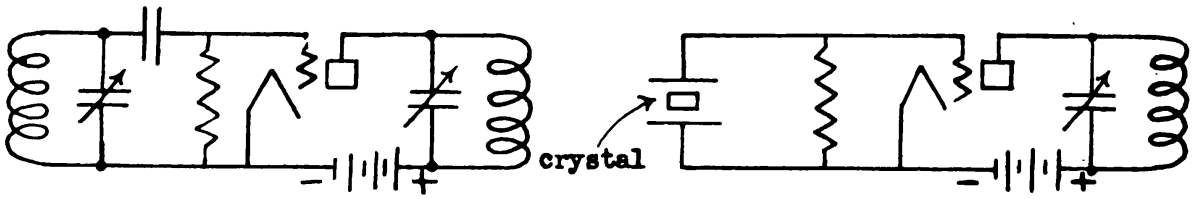
forms a condenser. But its action, when voltages of certain frequencies are connected across it, is not at all like a condenser.

PARALLEL INDUCTANCE AND CAPACITANCE



At its resonant frequency a crystal may be substituted for the inductor and condenser in the tuned grid circuit of an oscillator.



tuned plate—tuned grid crystal controlled

When the plate circuit is resonant at a frequency near the natural vibration frequency of the crystal, the frequency of oscillation will be controlled by the crystal. Oscillation will not occur if the resonant frequency of the plate circuit is made far different from the crystal frequency, especially if the plate circuit is resonant at a lower frequency than the crystal.

In adjusting this type of crystal controlled oscillator, the plate circuit is brought to resonance with the crystal, then backed off to a slightly higher frequency to insure reliable operation.

COMMON USES

Quartz crystals are used where very exact control of oscillator frequency is required.

Each crystal permits oscillation on only one frequency. A large number of crystals would be required for an oscillator which is to work on any one of a large number of frequencies. Consequently, in many types of equipment it is desirable to use an oscillator which can be varied in frequency.

EXAMPLE PROBLEMS

1. Will a crystal control frequency equally well if it is placed in the plate rather than the grid circuit of an oscillator tube?

   ANS: Yes. However the power in the grid circuit of a tube is much lower

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than the power in the plate circuit. There is much less possibility of fracturing the crystal when it is used in the grid circuit.

2. What care should be used in handling a crystal?

ANS: Quartz crystals are quite fragile. They are ordinarily enclosed in dust proof or evacuated holders. These should not be tampered with as long as the crystal operates normally. If it is necessary to clean the crystal itself, carbon tetrachloride can be used, handling the crystal only with a clean, lintless rag. Evacuated holders should never be opened.

3. Are crystals used to control oscillation at very high frequencies?

ANS: Crystals for frequencies above 8 or 10 megacycles are very thin. It is difficult to grind them to the exact desired thickness. In addition, they are so fragile that they are seldom found in usual equipment.

CLASSROOM PROBLEMS

1. An inductor and variable condenser are used in the plate circuit of a crystal controlled oscillator. They are adjusted to resonance at the crystal frequency For stable operation, should condenser capacity be increased slightly or should it be decreased slightly?

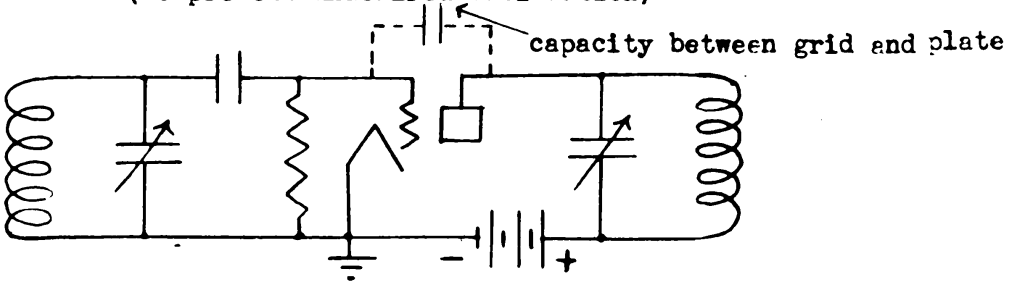
ANS:_____

2. A certain crystal controlled oscillator has a power output of 3 watts with a plate voltage of 300 volts. Increased power could be obtained by increasing the plate volatage. Might this be undesirable from the standpoint of crystal life? Why?

ANS:_____

NEUTRALIZATION

(To prevent undesired oscillation)



An amplifier designed to amplify at only one particular frequency will have tuned circuits connected to its grid and plate. These are both tuned (adjusted) to the same resonant frequency. This circuit is actually an oscillator circuit. Oscillation will occur if grid and plate circuits are tuned to a high enough frequency to cause very much energy to be transferred through the capacity between grid and plate in the tube.

Oscillation upsets the operating characteristics of an amplifier. It can be pre-

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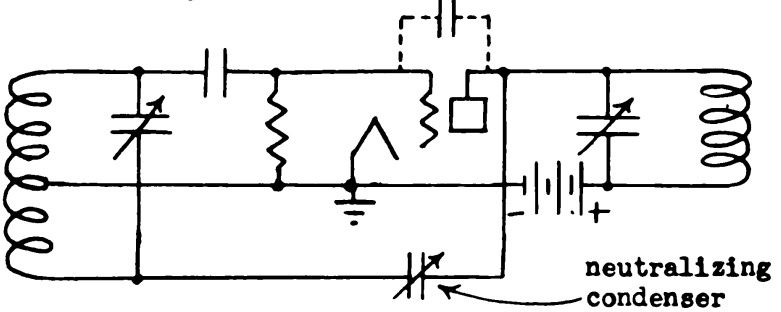
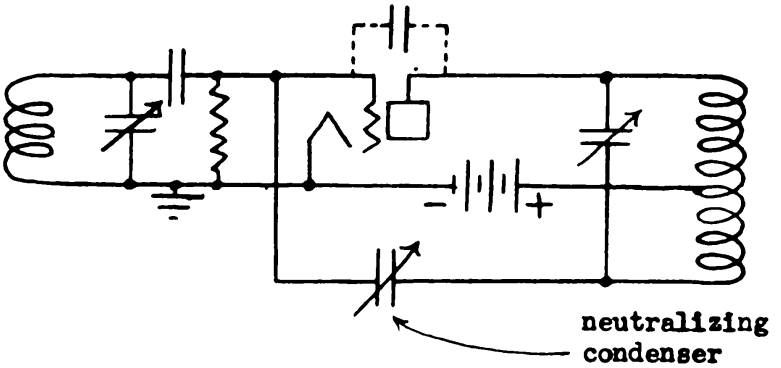
vented if the feedback from plate to grid is "neutralized" or balanced out.



The amplifier is "neutralized". The cathode is connected to the center of the grid tuned circuit inductor. The neutralizing condenser is adjusted to be equal to the grid-plate capacity of the tube.

The plate will transfer voltage through the tube capacity of the grid. However it will also transfer an equal voltage to the bottom of the grid coil through the neutralizing condenser. These voltages at the two ends of the grid inductor will produce opposite and equal fields which cancel.

Neutralization by use of a center-tapped grid inductor is called "grid neutralization".



Neutralization can be accomplished by using a center-tapped plate circuit inductor. For any voltage at one end of the plate inductor, there is an equal voltage with opposite polarity at the other end. The grid gets a positive voltage through the tube equal to the negative voltage through the neutralizing condenser. Thus they cancel.

Neutralization by use of a center-tapped plate inductor is called "plate neutralization".

EXAMPLE PROBLEM

1. Why is neutralization more important for high than for low frequency amplification?

   ANS: The capacity between the grid and plate of a vacuum tube is not very large (usually from 2 to 20 mmfd.). At low frequencies, this small capacity has a high impedance and does not pass much energy back to the grid circuit. At high frequencies, the impedance is lower and oscillation will result quite readily.

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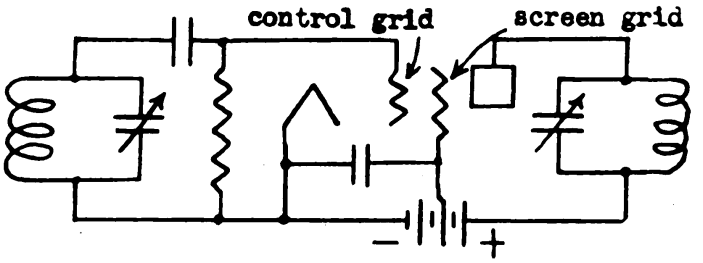
CLASSROOM PROBLEM

1. A tube will not start to oscillate by itself when fixed grid bias is large enough to prevent plate current flow. Still, it is important to neutralize an amplifier even though it has a large amount of fixed negative bias. Why?

ANS:_____

_____

SCREEN-GRID TUBES



Oscillation cannot occur if the capacity between grid and plate is reduced to a very small amount. This can be accomplished by placing a screen between the grid and plate and connecting this screen to the cathode. Such a screen is called a "screen grid". The original grid is called the "control grid" to distinguish it from the screen grid. This is a "four element" tube or "tetrode".

The screen grid is connected to the cathode through a condenser so it will act as a screen only so far as AC is concerned. It is connected to a DC voltage somewhat lower than that of the plate so it will not hinder the flow of electrons between cathode and plate.

A large amount of amplification can be obtained with a screen grid tube. There is little tendency for the changes in plate current to affect the grid and produce oscillation.

EXAMPLE PROBLEM

1. What happens if the screen grid is operated at a higher positive voltage than the plate?

   ANS: The positive screen causes the electrons from the filament to be traveling very fast when they hit the plate. The impact dislodges some electrons from the plate and these are attracted back to the more positively charged screen. The result is that screen current is high and plate current is low. Little power is supplied to the load attached to the plate circuit.

CLASSROOM PROBLEM

1. Why is the screen grid made of a network of wires rather than a plate of metal?

ANS:_____

_____

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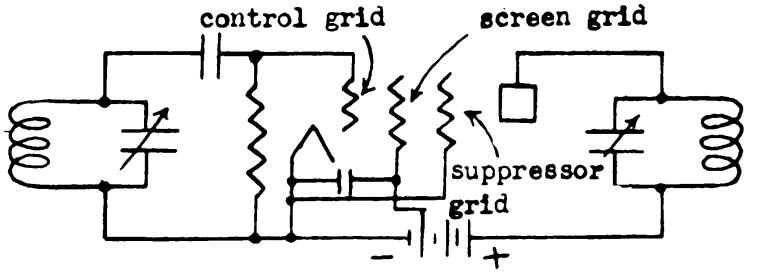
FIVE-ELEMENT TUBES



During a portion of the AC cycle, the plate voltage may drop to a lower value than the fixed screen voltage. This causes loss of plate current at such times.

A grid placed between screen grid and plate and connected directly to the cathode is called a "suppressor" grid. The suppressor grid is made with rather large openings so it will not hinder the flow of electrons between cathode and plate. It effectively prevents the flow of electrons from plate back to screen grid when the plate is at a lower positive voltage than the screen grid (during the negative part of the AC plate voltage cycle).

This is called a "five element" tube or "pentode".

Pentodes are often used in preference to four element tubes because greater efficiency can be had per tube.

EXAMPLE PROBLEM

1. Is the suppressor grid always connected directly to the cathode?

   ANS: In some pentodes the suppressor grid is connected directly to the cathode inside the tube. Occasionally, a small voltage may be placed on the suppressor grid, but this is not usually done.

CLASSROOM PROBLEM

1. In some tubes, the control grid connection is brought out the top of the tube separate from the connections to the other elements. Why is it so separated?

   ANS:_____

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HOMEWORK

1. Why will changing the resonant frequency of the plate circuit have little effect on the frequency of a crystal oscillator?

   ANS:_____

2. Care must be taken to apply only low RF voltages to a crystal, especially when the frequency of such voltages is near the natural frequency of the crystal. Why?

   ANS:_____

3. What would probably happen if you dropped a crystal, whether it is in its holder or not?

   ANS:_____

4. If the tap on the grid inductor of a grid neutralized amplifier is not at the center of the coil, could the capacity of the neutralizing condenser be changed accordingly to maintain neutralization?

   ANS:_____

5. Why are oscillator circuits not neutralized?

   ANS:_____

6. Why can greater plate efficiency be obtained with a pentode than a screen grid tube?

   ANS:_____

7. Why is little useful power delivered by a screen grid tube when screen current is high and plate current low?

   ANS:_____

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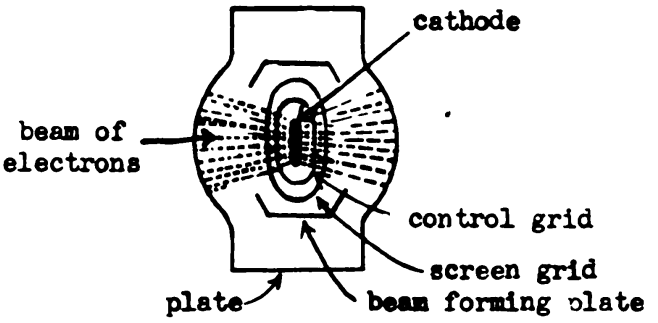
OTHER MULTI-ELEMENT TUBES



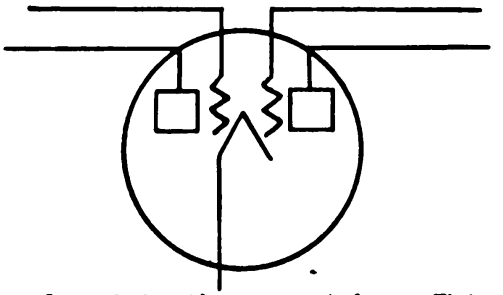
BEAM POWER TUBE

The beam forming plates are connected to the cathode.

The electrons leaving the cathode are formed into two narrow streams directed at the plate. Few of them hit the screen on the way to the plate. The strong concentration of electrons near the plate prevents the return of many to the screen during the time the plate is at a lower positive voltage than the screen.

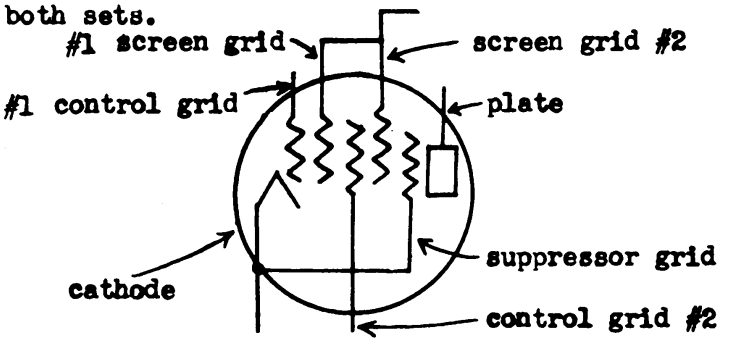
This is called a "beam power" tube. It accomplishes the purpose of preventing the return of electrons from plate to screen grid.

Beam power tubes are connected in a circuit in the same manner as four element tubes. They give results similar to pentodes. Beam power tubes are often used in place of pentodes.



Two triodes are sometimes placed in the same tube. This conserves space and reduces the number of tubes. This is called a "twin triode" tube.

Some twin triodes use separate cathodes for each set of elements. Others use the same cathode for both sets.



One type of special purpose tube is built with two control grids. An AC voltage connected to control grid #1 will control the flow of electrons from the cathode. Another AC voltage can be connected to control grid #2. The current which flows

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through the plate is controlled by the action of both AC voltages.

This is called a "converter" or "mixer" tube. Other types of converter tubes are built with even more grids.

Many other special types of tubes are used, especially in small radio receivers where compactness is important.

Tubes which are to handle large amounts of power are generally built with only three or four elements.

EXAMPLE PROBLEM

1. Name the essential types of radio tubes.

   ANS: All radio tubes are essentially diodes, triodes, tetrodes or pentodes. Tubes having a large number of elements are simply variations or combinations of these types.

CLASSROOM PROBLEMS

1. What type of single tube would be suitable for operation as an audio frequency class B amplifier ?

   ANS:_____

2. What type of single tube can be used for a full wave rectifier ?

   ANS:_____

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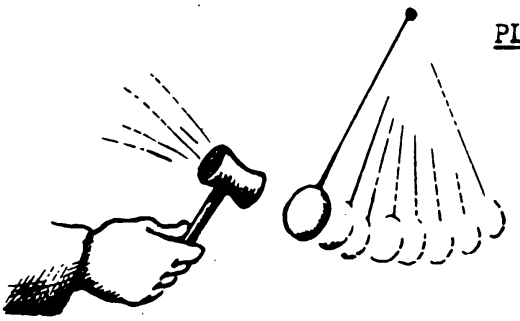
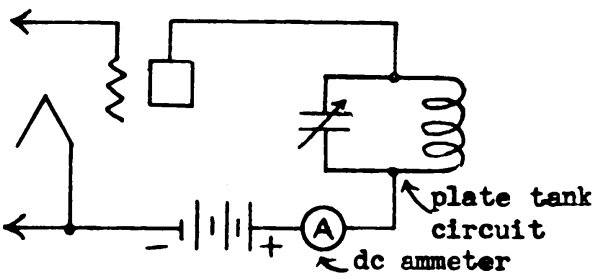
PLATE TANK CIRCUITS

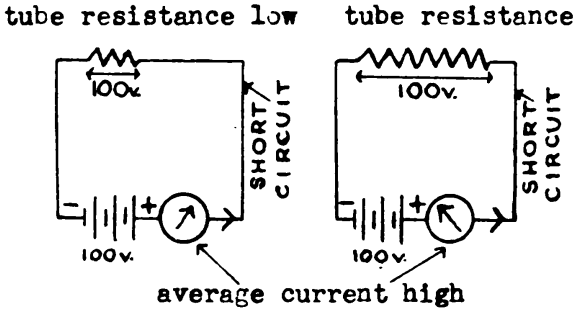




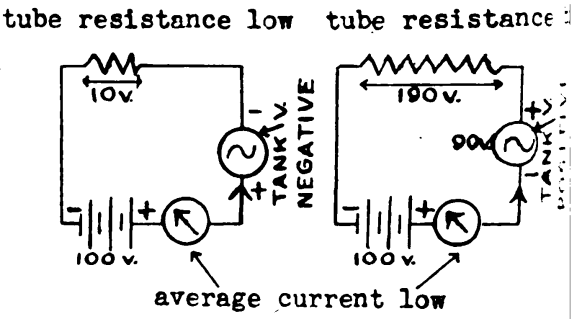
A pendulum requires only one impulse during each swing to keep it in time.

A parallel resonant circuit requires only one pulse of voltage during each cycle to keep the current oscillating back and forth between inductor and condenser. The tuned circuit builds up high voltages from these impulses.

A parallel resonant circuit used with a vacuum tube is called a "tank circuit".



Tank Resonant Above Or Below Driver Frequency



Tank Resonant At Driver Frequency

Since plate current can flow in only one direction, its average value can be indicated by a DC ammeter or milliammeter.

When the tube grid is driven by AC, the tube resistance between filament and plate alternately is low and then high. The rate of change of this resistance is governed by the frequency of the grid driving voltage.

If the plate tank circuit is resonant at a frequency quite different from the frequency of the driving voltage, it acts as practically a short circuit. Full battery voltage is on the plate at all times. This causes the plate current to vary as the tube resistance is varied. Average plate current is quite high (left diagrams above).

If the plate tank circuit is resonant at the frequency of the driving voltage, the parallel resonant circuit can be considered as an AC generator. At the instant the tube resistance is low (grid positive), the voltage across the tank opposes the battery voltage. Plate current is low. At the instant the tube resistance is high (grid negative), the voltage across the tank reaches a peak in the positive direction, aiding the battery. Plate current still does not become very high, since there is now high tube resistance. Average plate current is low (right hand diagrams above).

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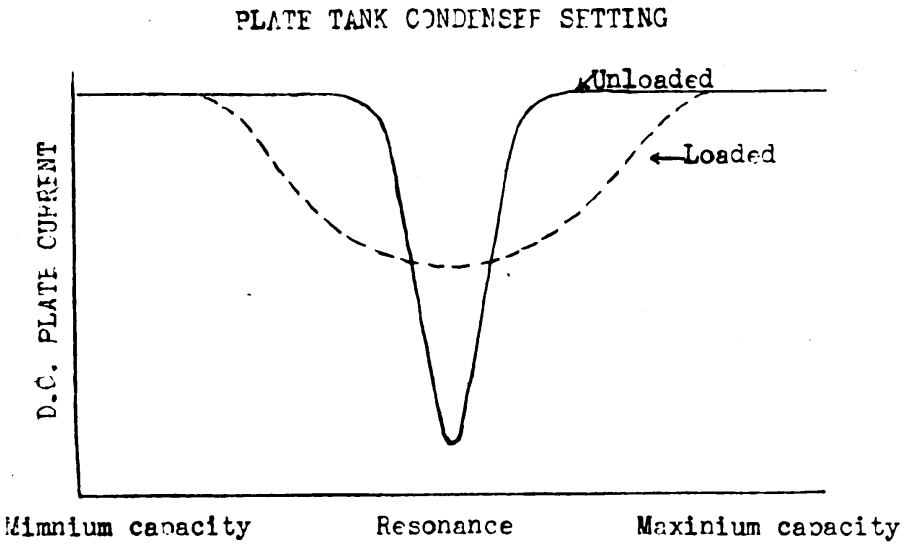
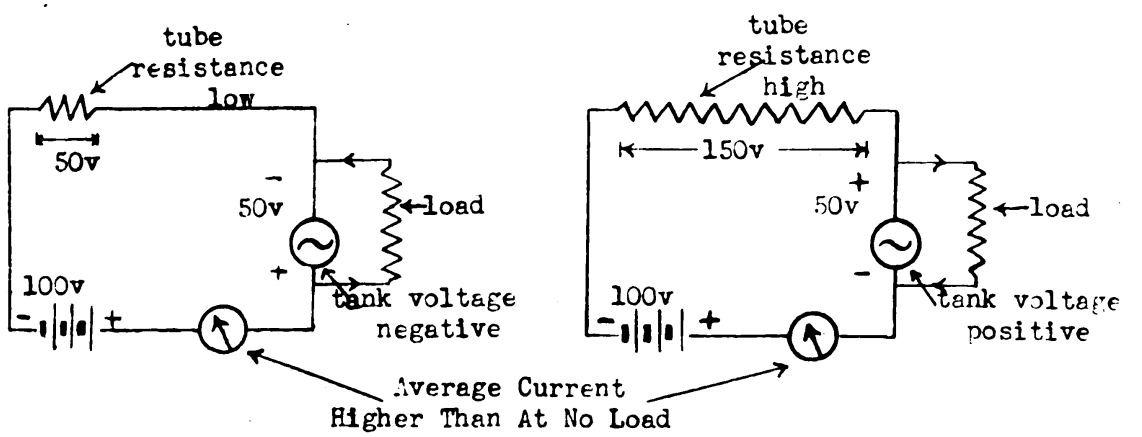
The effect of the resonant tank circuit is to vary the plate voltage above and below the battery voltage. This variation may be as much as from near zero to near twice battery voltage.



When the variable condenser in a plate tank circuit is rotated, there is an abrupt dip in DC plate current as the tank reaches resonance at the driver frequency.

Further rotation of the condenser causes plate current to return to a steady, rather high value.

The high off-resonant plate current flows through the tube resistance. The tube plate will heat badly at off-resonance settings of the plate tank circuit in transmitter tubes. Output will be very low since there is little voltage across the output tank circuit.



TANK RESONANT AT DRIVER FREQUENCY

A resistor connected across the plate tank circuit acts as a load as far as AC is concerned. It will draw power whether the tank voltage is positive or negative. This causes a reduction in the voltage across the tank. Average plate current is higher than with no load on the tank.

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EXAMPLE PROBLEMS

1. Why must care be taken when tuning the plate tank of a vacuum tube?

   ANS: Off-resonance plate current is very high and the power used is dissipated almost entirely in the tube. Voltage should be applied to the tube only for short periods until the resonant setting is located. Otherwise there is danger of damaging the tube

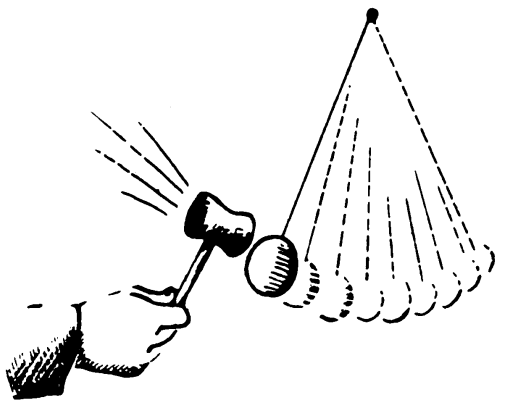
2. Why is the current flowing between the condenser and inductor in a tank circuit higher at no-load than with a load connected?

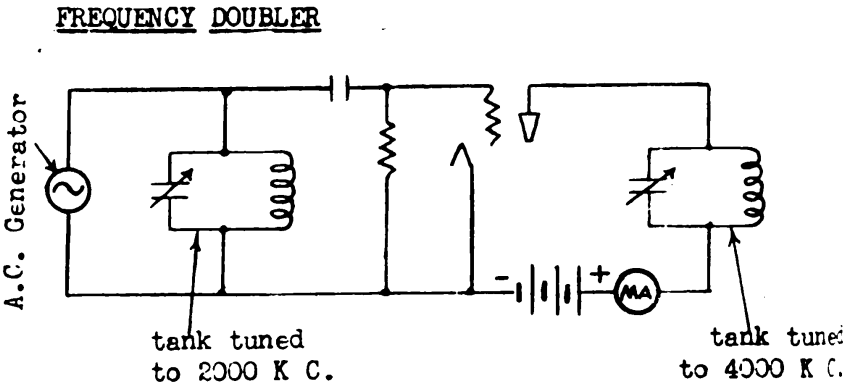
   ANS: When a load is connected, the AC voltage across the tank circuit is reduced. This causes less AC current to flow in the tank.

CLASSROOM PROBLEM

1. Why does a plate tank condenser sometimes flash over when there is no load connected to the tank?

   ANS: _____





A pendulum will keep swinging even though it only receives an impulse for <u>every other swing</u>. A stronger impulse is required than when there is one for each swing.

Current will oscillate back and forth in a parallel resonant circuit even though it only receives an impulse of voltage every other cycle. These impulses must be stronger than when there is one every cycle.

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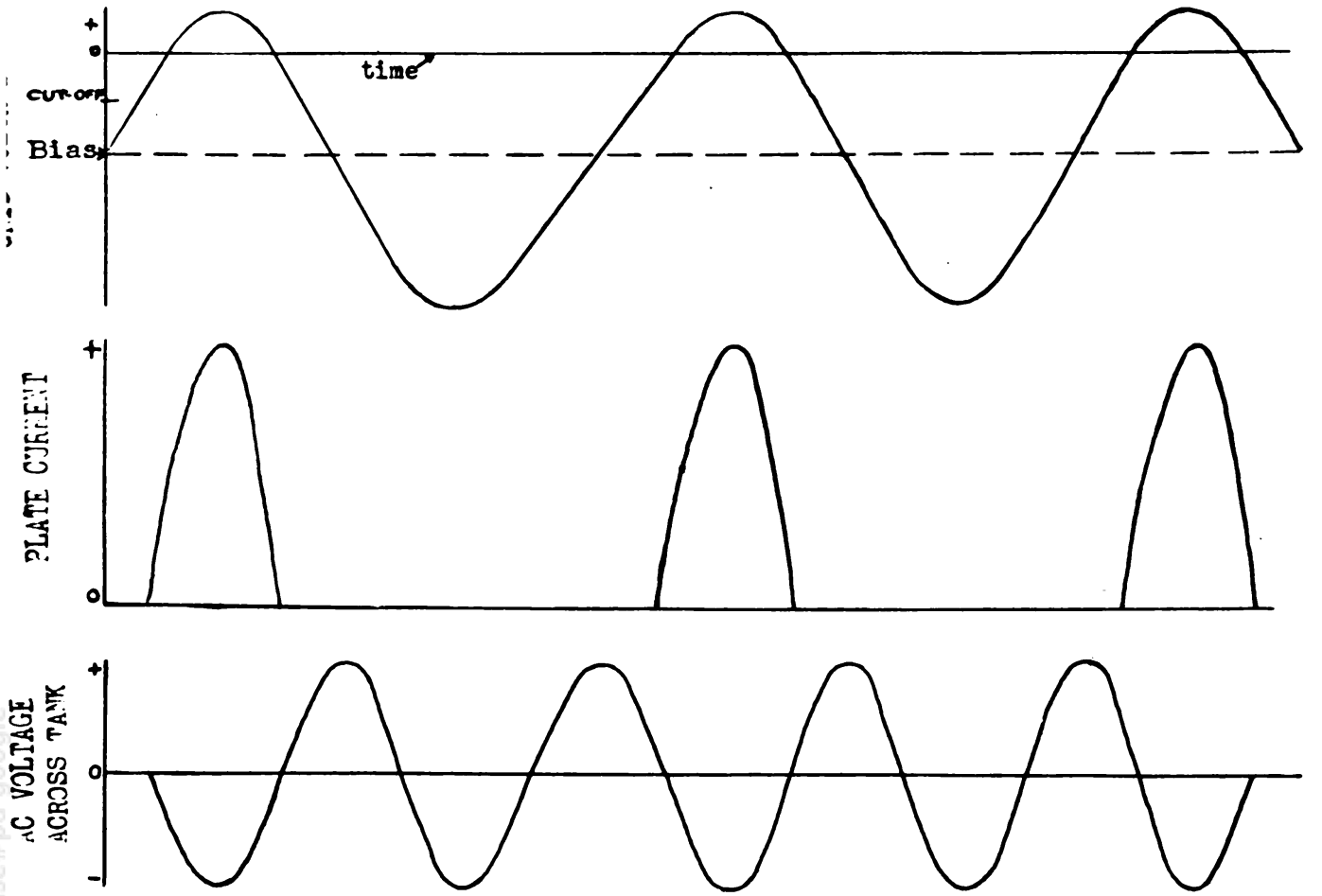

A Class C amplifier gives a short but quite strong current pulse for each cycle of the driving voltage.

When the plate tank is tuned to resonance at exactly twice the driver frequency, these pulses will cause oscillation in the tank circuit.

A vacuum tube operated in this manner is called a "frequency doubler".

The efficiency of a doubler tube is much lower than when the output is at the same frequency as the input. No neutralization is required, since the plate and grid circuits are at different frequencies. Neutralization will improve efficiency.

Maximum efficiency is obtained when there is large negative bias on the grid, causing the plate current pulses to be of very short duration. A rather large amount of driving power is required with high negative bias. Tube efficiency may be as much as 50% under this condition.

A vacuum tube may also be used to triple or quadruple frequency. In this case, tube efficiency becomes very low since there is only one pulse of current for every three or four cycles. Driving power requirements become more severe. More driving power may be required than is obtained in the output load.

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EXAMPLE PROBLEM

1. Why are frequency doublers used in many aircraft radio transmitters?

   ANS: The use of one or more frequency doublers permits the use of a relatively low frequency oscillator even though output is required at hign frequency. This is especially useful when crystal oscillators are used, since there is a limit to the upper frequency at which crystals are practical.

CLASSROOM PROBLEM

1. Crystals are easily damaged if subjected to large radio frequency currents. Does this suggest another advantage of using a doubler between a crystal oscillator and a high power amplifier in a transmitter?

   ANS:_____

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RADIO PRINCIPLES

HOMEWORK

1. What elements are contained in a duplex-diode (twin diode) tube? In a duplex-diode triode tube?

   ANS:_____

   _____

2. What is the usual purpose of a tube having two control grids?

   ANS:_____

3. A single tube cannot be used as a Class B amplifier at audio frequency because the negative half of each driver cycle is not reproduced by the plate current. Why can a single tube be used as a Class B amplifier at radio frequency?

   ANS:_____

4. When is the RF current in a plate tank circuit highest, at no-load or full load?

   ANS:_____

5. Why is it more desirable to double frequency in a tube handling low power than high power?

   ANS:_____

6. The plate tank circuit of a Class C amplifier can be tuned to a frequency ten times that of the driving frequency, and output will be obtained on the high frequency. Why is this never done in a transmitter?

   ANS:_____

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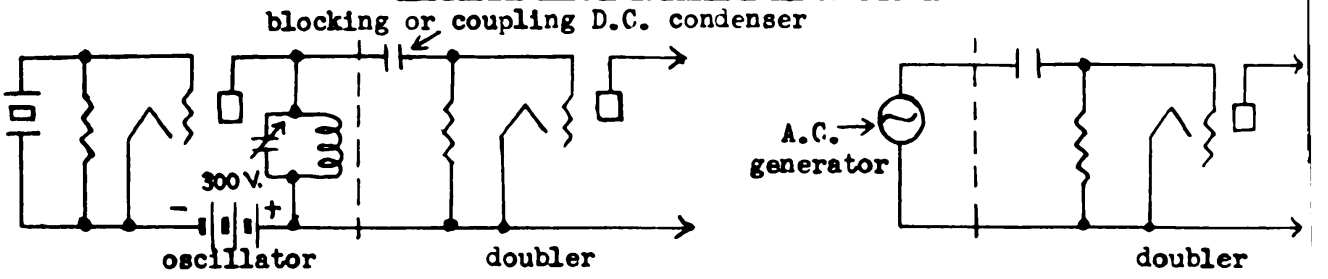
COUPLING R. F. CIRCUITS BY CAPACITY

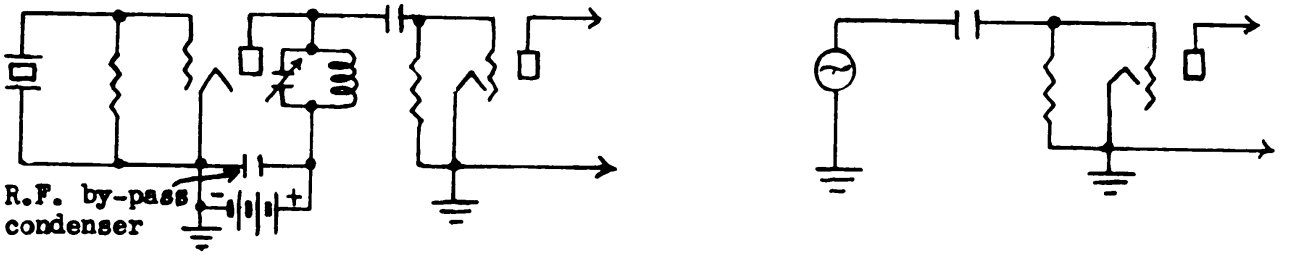


ACTUAL CIRCUIT — EQUIVALENT CIRCUIT

The output of an oscillator is the radio frequency (RF) AC voltage across its plate tank circuit. This tank circuit can be likened to an AC or RF generator.

The output is connected to the grid circuit of the following tube. A condenser in series with the doubler tube grid prevents the bias voltage from being short-circuited through the oscillator plate tank. It also prevents the oscillator plate voltage from being connected directly to the doubler grid. This is a "blocking" or "coupling" condenser.

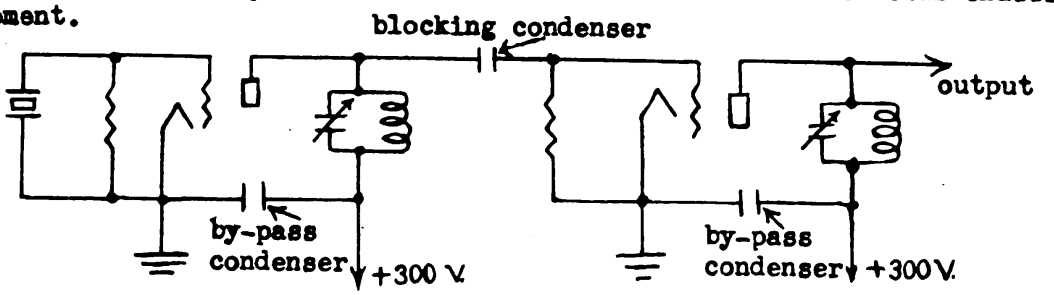
FILTERING CIRCUITS



ACTUAL CIRCUIT — EQUIVALENT CIRCUIT

There is a large RF voltage drop across the plate tank circuit. There is some RF voltage drop across the plate battery as it has some resistance. A condenser connected across the plate battery provides an easy path for the RF current so it will not have to pass through the battery.

The "ground" connection symbol indicates connections made to the metal chassis of the equipment.



The plate battery now has virtually no RF across it. The same DC plate supply (battery) can be used for both tubes.

The by-pass condensers provide a path for the RF current so it will not stray into the DC plate supply. It allows AC current to return to each tube filament circuit and ground.

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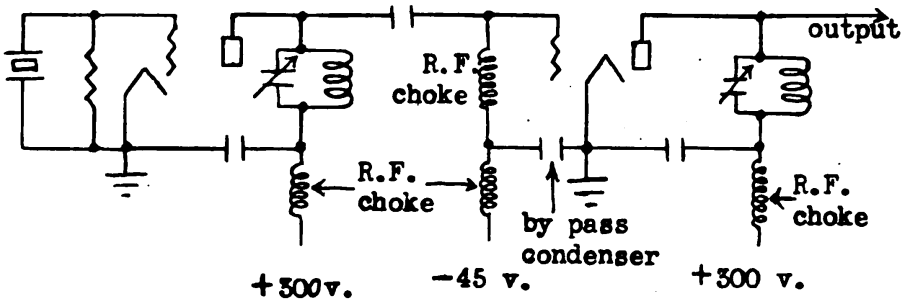
The negative terminal of the high voltage DC supply is connected to "ground" or the common ground connection. The positive DC supply can go to any desired number of tubes.

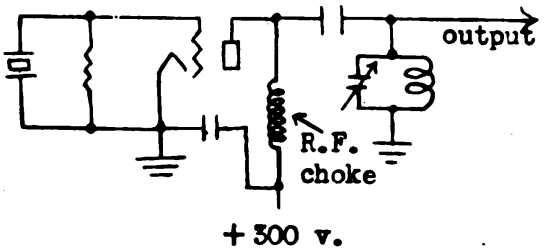


Further insurance against RF voltages straying where they are not wanted lies in the use of an "RF choke" in series with the wire leading to the power supply.

An RF choke is an inductor designed to have very high reactance in the general frequency range to be used in the equipment. Only a negligible amount of RF current will be able to pass such an inductor even though it is not actually tuned.

RF chokes are often used in connection with fixed bias on the grid of a tube. Such a choke prevents the loss of RF voltage at the grid of the tube, but provides a low resistance path for the DC bias to the grid. A by-pass condenser connected from the end of the choke to ground effectively protects the negative bias supply from any RF which might leak through the choke.

The positive terminal of the bias battery or supply is connected to the common ground terminal. One battery may be used to provide bias for several tubes when it is so isolated from the effects of RF voltages.



It is sometimes desirable to connect one end of the plate tank directly to ground. The blocking condenser prevents short-circuiting the DC plate voltage. The RF choke prevents the high voltage RF at the tube plate from entering the high voltage DC power supply. This choke also prevents the loss of RF plate voltage.

EXAMPLE PROBLEM

1. What factors must be considered in the use of blocking condensers, by-pass condensers and RF chokes?

   ANS: RF will pass through condensers but not through RF chokes. DC will pass through RF chokes but not through condensers.

   The components must always be arranged so the RF path is complete and does not pass through the power supply. The DC path must be complete so each tube receives the necessary DC grid and plate voltages.

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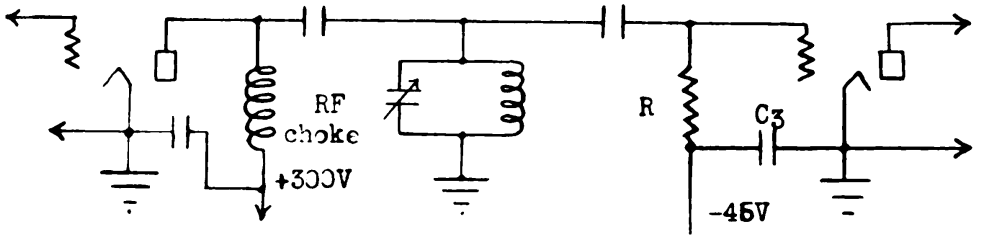
CLASSROOM PROBLEMS

1. Explain the purpose of the blocking condensers, by-pass condensers, RF choke and resistor in the following circuit:



ANS:

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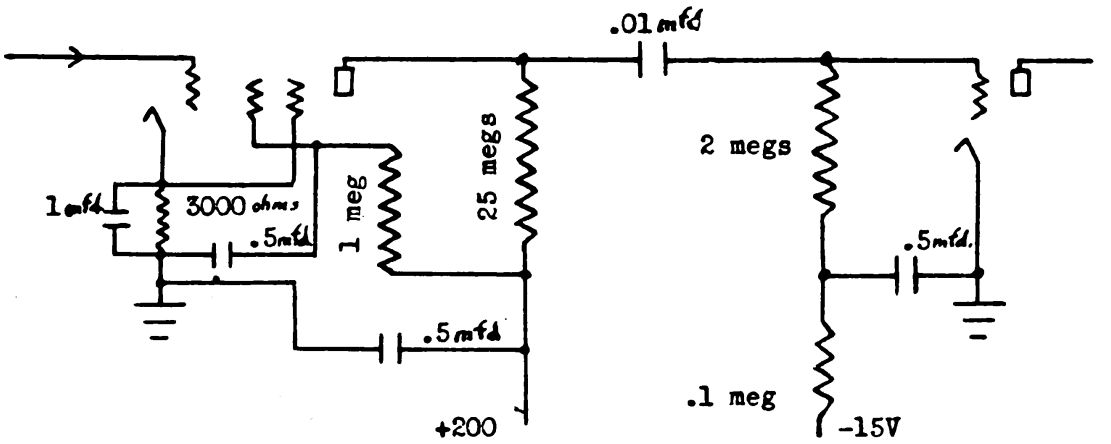
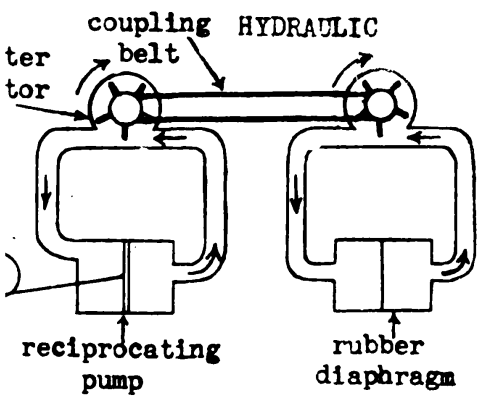
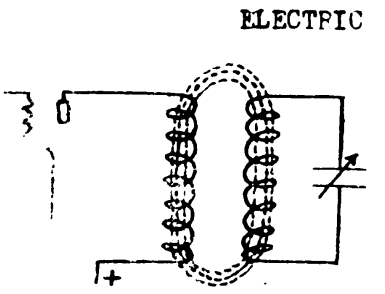
2. Explain the purpose of <u>each</u> element in the following common type of amplifier:



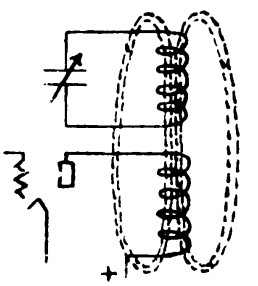
ANS:

<u>INDUCTIVE COUPLING OF R. F. CIRCUITS</u>





field through both inductors



field through both inductors

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When the flywheels of two water motors are connected by a belt, the rotation of one causes the other to rotate. Thus, energy is transferred from one system to the other.

Maximum energy transfer occurs when the belt is tight and the second circuit is hydraulically resonant at the same frequency as that of the pump.

When the belt is loose, little energy will be transferred. Crossing the belt does not affect the amount of energy transferred. It simply reverses the direction of flow in the second circuit.

Similarly, when two inductors are placed close together, they are linked together by a common magnetic field. Energy is transferred from one circuit to the other.

Maximum energy transfer occurs when the inductors are close together and the second circuit is resonant at the same frequency as that of the voltage in the first.

When the inductors are moved apart, the transfer of energy becomes less. Reversing the direction of the winding in the second coil does not affect the amount of energy transferred. It simply reverses the direction of the current in the secong circuit.

Coupling (transferring energy) by means of the fields of inductors is called "inductive" coupling.

EXAMPLE PROBLEM

1. Suppose the cylinder in the second hydraulic circuit is made quite small and the water motor flywheel quite heavy. This maintains hydraulic resonance at the same frequency as before. What is the effect on the pressure and flow?

   ANS: This causes maximum pressure to be a great deal higher and maximum flow to be a great deal less. Energy transferred is still the same. Pressure and flow in the second circuit may be quite different from those in the first circuit.

CLASSROOM PROBLEMS

1. What is the effect on the voltage and current in the second circuit when the capacity is reduced and inductance correspondingly increased? Is the power in both circuits equal?

   ANS:_____

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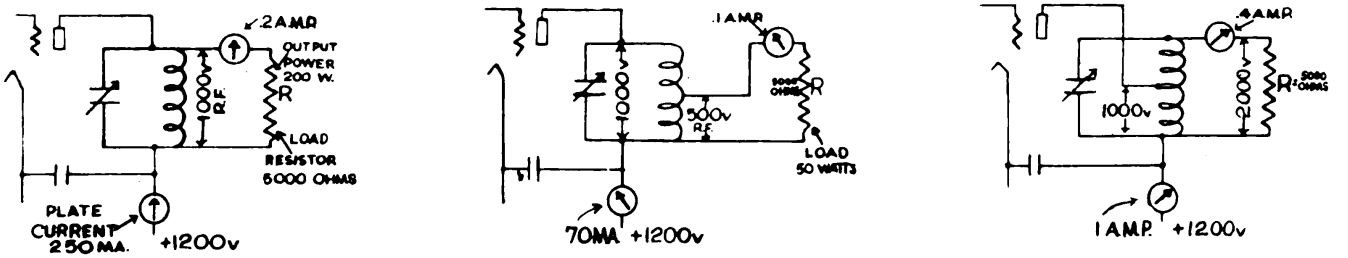
2. What is the effect on the voltage and current in the second circuit when the inductance is reduced and the capacity correspondingly increased?

ANS: _____

_____

_____

DIRECT COUPLING OF TANK CIRCUIT LOADS



A load resistor connected across the plate tank inductor will receive the full RF voltage of the tank circuit.

If the RF voltage across the tank circuit is 1,000 volts, a 5,000 ohm load would draw a load current of.2 ampere.

The same load resistor can be made to draw much less power from the tank circuit by connecting it across only part of the inductor as shown at the center above.

Thus, connecting the load half way down the tank inductor will reduce the RF voltage across the load to 500 volts. This reduces the current through the load to .1 ampere. The load now receives only 50 watts.

Finally, as shown at the right, the plate can be tapped down on the inductor, giving equally high load voltage. This voltage is greater than the RF plate voltage. Current is now .4 ampere and the RF load power is 800 watts.

Moving the load connection to a different position on the inductor changes the amount of power delivered to the load.

The plate tank condenser serves only to keep the tank circuit in resonance. It is always set at the point of lowest dip of DC plate current.

Transfer of energy by direct connection is called "direct" coupling.

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EXAMPLE PROBLEM

1. Suppose a 10,000 ohm load resistor is used in the above circuit. Where would it be connected on the inductor to draw a power of 100 watts?

   ANS: It would be connected across the entire plate tank inductor. Then, RF voltage across the load is 1,000 volts and current through the load is .1 ampere. Power drawn by the load is 100 watts.

CLASSROOM PROBLEMS

1. A DC milliammeter is used to indicate DC plate current. What kind of ammeter is required to indicate current drawn by the load?

   ANS:_____

2. How much DC power is supplied direct to the load?

   ANS:_____

3. How much DC power is required in each case illustrated above? What is the efficiency in each case?

   ANS:_____

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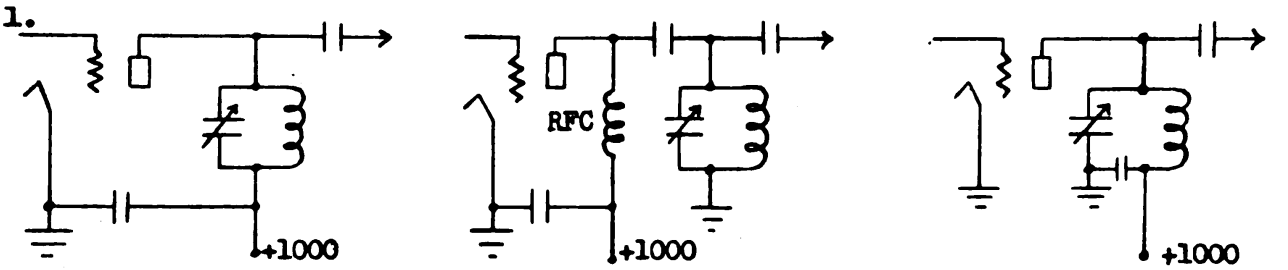
HOMEWORK

1.



A B C

The tank tuning condenser in circuit "C" must be able to stand a higher voltage without flashover than the ones in circuits "A" and "B". Why?

ANS:_____

2. Refer to diagrams in Problem 1. What precaution must be taken if the tuning condenser in circuit "A" is to be mounted on a metal panel? Would it be safe to touch the condenser shaft, which is connected to the rotor plates?

ANS:_____

3. Refer to diagrams in Problem 1. When using circuit "B" or "C", the tuning condenser is often mounted directly on a metal panel, with the shaft and rotor plates connected to ground. Why is this impractical with circuit "A"?

ANS:_____

4. Refer to diagrams in Problem 1. Which circuit is least likely to cause a fatal shock if the tank inductor is touched inadvertently?

ANS:_____

5. Refer to diagrams in Problem 1. Why is circuit "A" or "B" generally preferable to circuit "C" where sizable amounts of power are handled by the tank circuit?

ANS:_____

6. A load is direct coupled to a plate tank circuit. How can you tell from the setting of the plate tank condenser whether the load is simply a resistance or if it contains reactance?

ANS:_____

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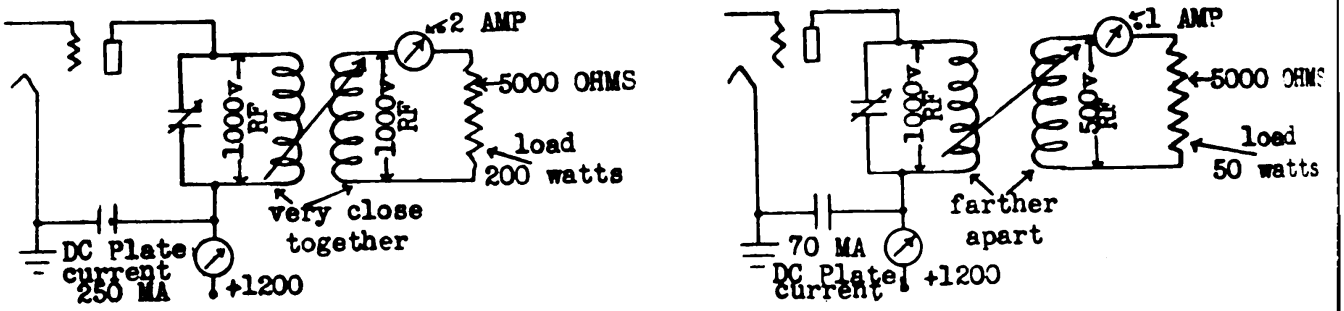
INDUCTIVE COUPLING OF TANK CIRCUIT LOADS



A load can be coupled to a plate tank by inductive coupling.

The arrow through the two inductors indicates that the amount of coupling can be varied by moving one inductor with respect to the other.

When the inductors are placed so their fields coincide, the load receives maximum power for the particular value of load.

As the inductors are moved apart, coupling (energy transfer) becomes less. Thus, the amount of power delivered to the load is reduced.

As with direct coupling, the sole purpose of the plate tank condenser is to keep the tank circuit in resonance at the proper frequency. It is always set at the point of lowest dip of DC plate current.

EXAMPLE PROBLEMS

1. Does turning the coils so one is at right angles to the other have the same effect as moving them apart?

   ANS: Yes. This prevents the magnetic field of the plate tank from setting up voltage across the inductor connected to the load.

2. Can the RF voltage across the load be varied by changing the number of turns in the inductor connected to the load?

   ANS: Yes. Fewer turns in the inductor will cause less voltage across the load. Additional turns will increase the voltage across the load, within reasonable limits.

CLASSROOM PROBLEMS

1. DC plate current decreases when the power drawn by the load is reduced. Will DC plate current be zero when no load is connected?

   ANS:_____

2. In the circuit shown above, the plate of the tube would heat excessively when a load of 200 watts is drawn from the plate tank but not when the load is reduced to 50 watts. Why is there less tube heating with a lighter load?

   ANS:_____

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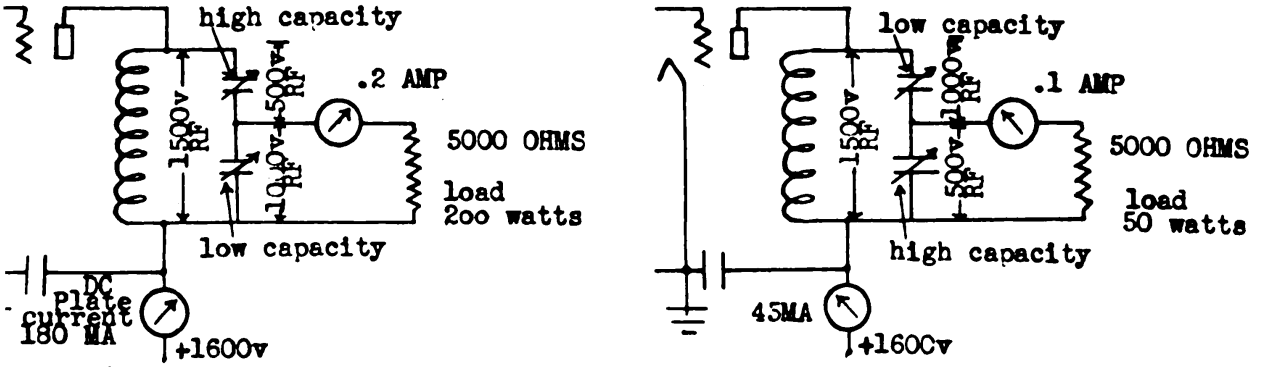
CAPACITIVE COUPLING OF TANK CIRCUIT LOADS



A load can be coupled to a plate tank by capacitive coupling.

Two tank condensers are used in series, with the load connected across one of them.

The voltage across the load is determined by the relative capacities of the two tank condensers.

When the condenser across the load has low capacity, its reactance is high. This means the RF voltage across the load will be high.

When the condenser across the load has high capacity, its reactance is low. RF voltage across the load is low.

The upper tank condenser is adjusted to bring the tank to resonance at the correct frequency. Every time the setting of the condenser across the load is changed, the second condenser must be reset to the point of lowest dip of DC plate current.

Thus, the lower condenser controls amount of coupling. The upper one is used to resonate the circuit.

EXAMPLE PROBLEM

1. Is this circuit suitable for a wide range of frequencies and loads?

   ANS: It will cover a wide range provided the inductance of the plate tank inductor can be varied. This is sometimes done by short-circuiting a few turns of the coil to reduce inductance. Wider changes are made by substituting other inductors in the circuit.

CLASSROOM PROBLEMS

1. Why is it <u>always important</u> to be sure the plate tank is tuned to resonance (lowest dip of DC plate current meter)?

   ANS:_____

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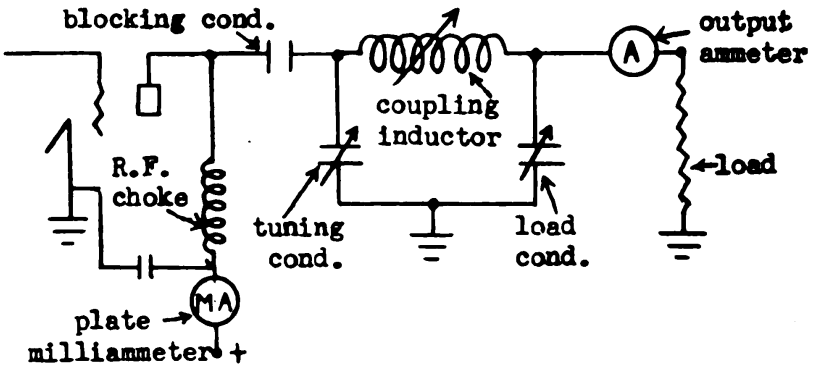
2. The tank condenser across which the load is connected is set for correct loading. What change should be made in the plate tank inductor if the second condenser does not have quite enough capacity to tune to resonance at output frequency?

ANS: _____

_____

PI NETWORK COUPLING OF TANK CIRCUIT LOADS

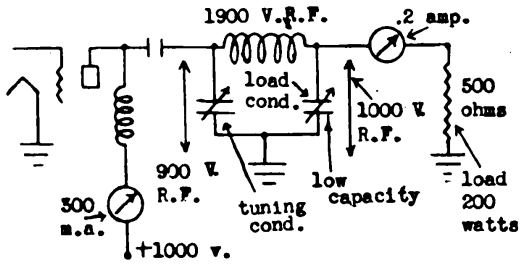


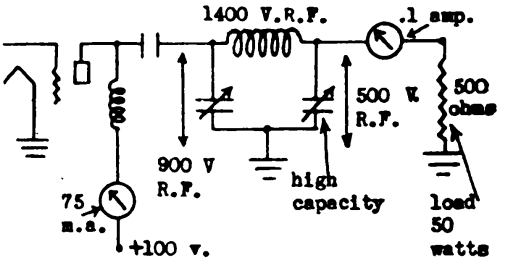
The DC plate voltage is supplied to the plate through the RF choke. The RF choke prevents the passage of RF voltage back into the plate supply.

The plate blocking condenser permits passage of the RF current between plate and coupling unit but blocks the DC so it will not appear across the load.

The plate tank inductor can be adjusted to the desired amount of inductance (indicated by the arrow through the inductor).

This is called a "pi network" coupling circuit because of its resemblance in a diagram to the Greek letter "π".





All of the tube's RF voltage is across the "tuning" condenser at all times. Adjustment of load voltage is made by changing the amount of load condenser capacity. This changes the relative amounts of voltage across the load and tuning condensers.

After the load condenser is set, the tuning condenser must always be adjusted to resonate the tank circuit (lowest plate current dip).

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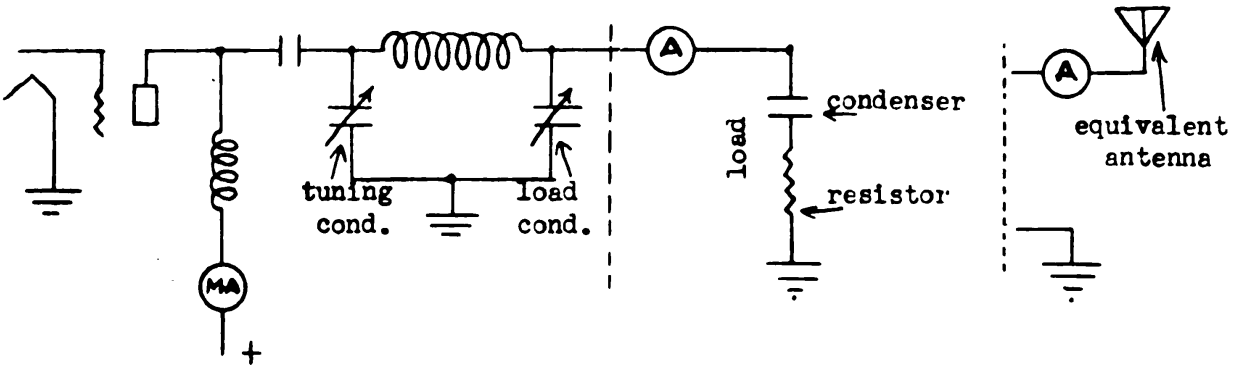
Pi networks are sometimes used for coupling between tubes in transmitters. They are widely used for coupling of transmitters to antennas.

EXAMPLE PROBLEMS

1. When is it necessary to vary the inductance in the coupling inductor?

   ANS: Some loads and frequencies may be beyond the range of the condensers. It is then necessary to change the amount of inductance. The inductor actually controls coupling.

2. What changes are necessary in adjustment if a condenser is placed in series with the load resistor as shown? Many antennas are equivalent to this type of load.

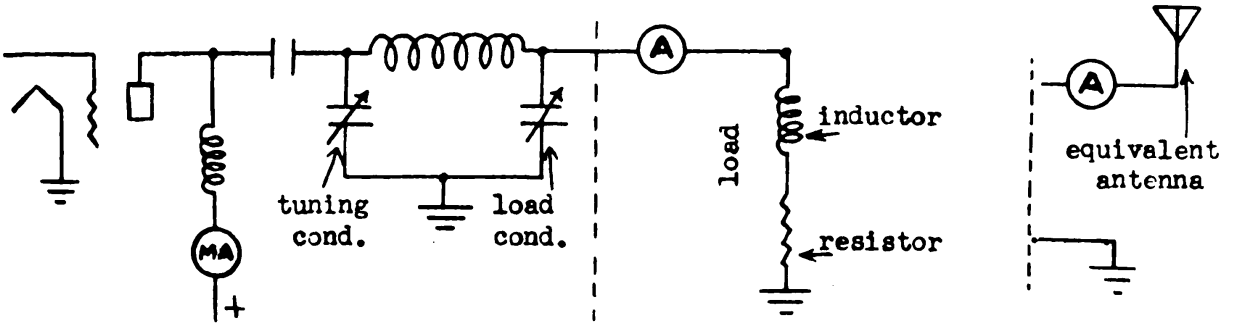


   ANS: The capacity of the load condenser must be reduced to compensate for the capacity which has been added in parallel with it.

   It must be further reduced to provide additional voltage across the load, since some voltage now appears across the reactance of the condenser in series with the resistor.

   The tuning condenser must then be readjusted to maintain resonance (plate current lowest dip).

3. What changes are necessary in adjustment if an inductor is placed in series with the load resistor as shown? Some antennas are equivalent to this type of load.



   ANS: The capacity of the load condenser must be increased to compensate for the inductance which has been added in parallel with it.

   However, there will be a voltage drop across this inductor so the load condenser capacity must be decreased somewhat to provide added load voltage.

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The actual net change in load condenser capacity will depend on how much inductance is placed in series with the load resistor.

Finally, the tuning condenser is readjusted to maintain resonance (plate current lowest dip).

CLASSROOM PROBLEMS

1. What change should be made in the inductance of the coupling inductor is unable to get sufficient load with the circuit tuned to resonance?

   ANS:_____

2. What change should be made in the inductance of the coupling inductor if unable to get sufficiently low loading with the circuit tuned to resonance?

   ANS:_____

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HOMEWORK

1. The DC power drawn by the plate of a vacuum tube is found by multiplying the DC plate current times the DC plate voltage. Why is this power always greater than the RF power output of the tube?

   ANS:_____

2. A load is inductively coupled to a plate tank circuit. How should the DC plate current change as the inductors are brought closer together? What precaution must always be observed regarding plate tank condenser setting to be sure the tube is operating at maximum efficiency?

   ANS:_____

3. In pi network antenna coupling, why is the tuning condenser always adjusted last?

   ANS:_____

4. In pi network antenna coupling, is the circuit properly adjusted if the tuning condenser is left alone and the load condenser adjusted for minimum plate current?

   ANS:_____

5. In pi network antenna coupling, what change is made in load condenser capacity to increase the power delivered to the load? To decrease the power delivered to the load?

   ANS:_____

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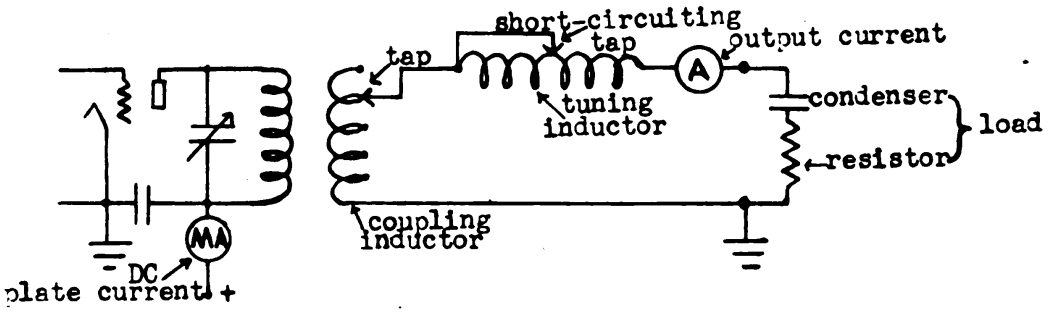
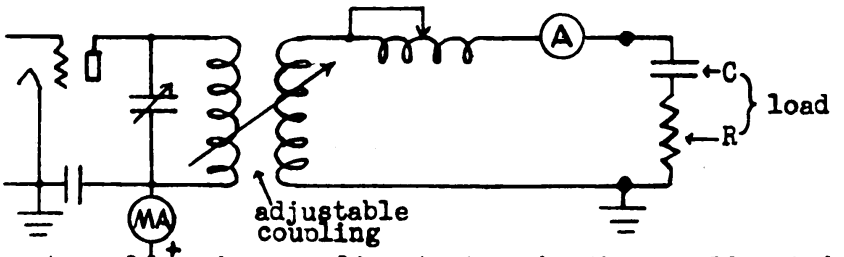
TYPICAL AIRCRAFT TRANSMITTER OUTPUT COUPLING



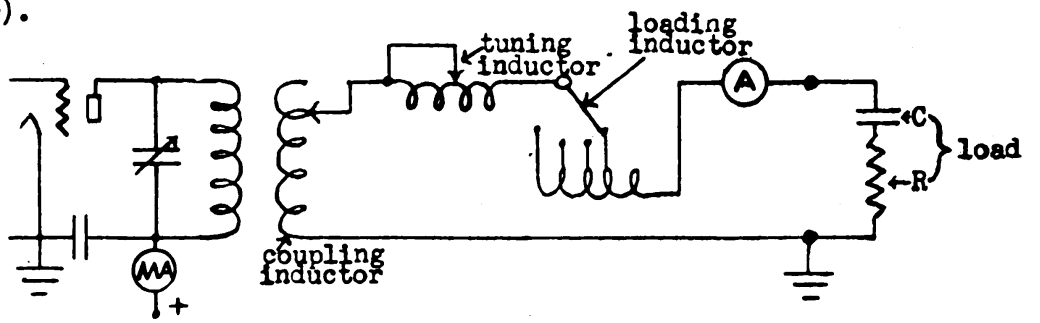
The output circuit is inductively coupled to the plate tank circuit. The amount of coupling can be varied by moving the tap on the coupling inductor to include more or less turns in the output circuit. More turns give more coupling. Fewer turns give less coupling.

Since the load has a capacitive reactance (capacity and resistance in series), it is necessary to add inductance to the output circuit to make it resonant at the output frequency.

The coupling is set at minimum. The plate tank is tuned to resonance (lowest DC plate current dip). The tuning inductor is adjusted for maximum output current. Coupling is now increased for maximum allowable plate current, making sure the plate tank is <u>exactly tuned to resonance</u> as coupling is increased.



Another system of varying coupling is to make the coupling inductor movable with relation to the plate tank inductor. Coupling can be varied by rotating the coupling inductor (or by moving it closer to or farther away from the plate tank inductor).



Sometimes the load has a very small series capacity (large capacitive reactance). A large amount of inductance (inductive reactance) must be used in the output circuit to obtain resonance. This can be obtained by connecting an additional inductor in series with the tuning inductor. The additional inductor often has only a few taps. Its inductance can be varied in rough steps by a switch. Finer adjustments of inductance are made with the tuning inductor.

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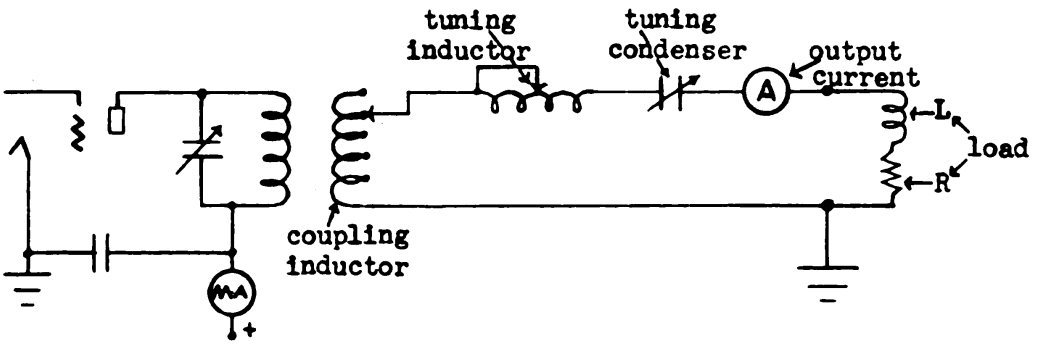
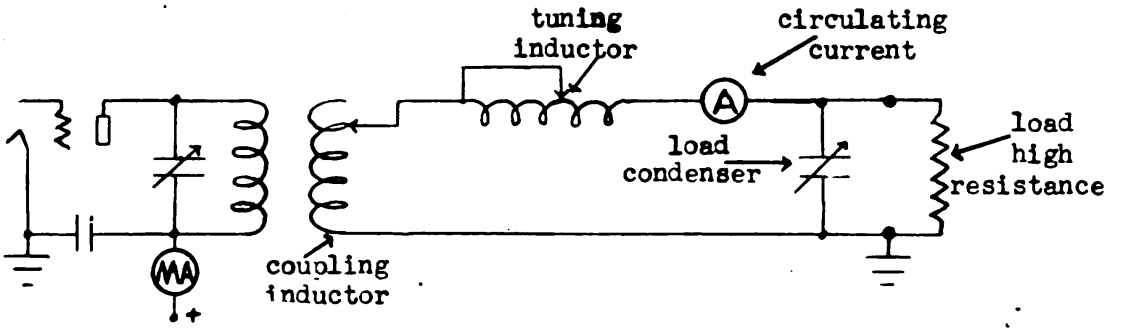
Finally, the plate tank condenser is reset to insure that the plate tank circuit is tuned to resonance (point of lowest DC plate current dip).



Sometimes, the load has inductive reactance (inductance and resistance in series). In this case, the coupling circuit must contain capacitive reactance in order to resonate at the desired frequency.

If the load contains a large amount of inductance (large inductive reactance), the tuning condenser must be set for low capacity (large capacitive reactance) to compensate. Most of the tuning inductor should be short-circuited so as not to add too much inductive reactance to the circuit.

If the load contains only a small amount of inductance (small inductive reactance), the tuning condenser is set for higher capacity (smaller capacitive reactance). More of the tuning inductor will be required for resonance.



When the load has a very high resistance, it is necessary to supply a high RF voltage across it in order to deliver much power.

This high RF voltage can be obtained by connecting a condenser across the output terminals. The capacity is adjusted until capacitive reactance is large enough to give the desired voltage across the load.

The ammeter is used to indicate the amount of circulating current in the output circuit. It indicates, by its maximum reading, when the circuit is tuned to resonance. Since circulating currents may become very high, the ammeter indicates when they are excessive.

The ammeter in the output circuit is no longer used to measure current to the load. If the ammeter were moved to the right to indicate only the load current, hardly any reading would be obtained on high resistance loads.

The lower the capacity of the load condenser, the larger is the voltage across the load resistance for a given circulating current. The higher the voltage, the greater is the power delivered to the load.

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Coupling is set at minimum. The plate tank is tuned to resonance. The load condenser is set near minimum capacity. The tuning inductor is adjusted for resonance either by indication of the RF ammeter or by maximum rise of plate current. If resonance is not reached, try again with more capacity. When resonance has been secured, do not touch the tuning inductor or load condenser again.

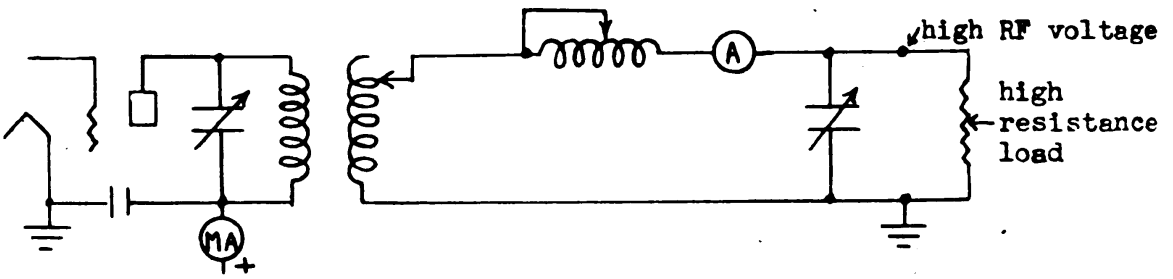
Coupling is now increased for maximum allowable plate current, making sure the plate tank is exactly tuned to resonance as coupling is increased. In case maximum coupling does not load the transmitter sufficiently, try another type of antenna coupling such as previously shown.

EXAMPLE PROBLEMS

1. May high voltages be developed across the inductors or condenser in an output coupling unit?

   ANS: Yes. When the reactance of an inductor is large, the RF voltage across it may become very high. This sometimes causes arcing over the insulation and failure of the transmitter , especially at high altitudes.

2. In the following circuit, what is a simple means of determining whether high RF voltage is being delivered to the load?



   ANS: High RF voltage will cause an arc when a pencil or screw driver with insultated handle is touched to the antenna post and drawn away slowly.

   An ordinary lead pencil can be used to draw an arc from the RF output terminal of the transmitter. The capacity of the body to ground provides a path for sufficient RF current to maintain a small arc.

   Relative amounts of RF voltage can be roughly determined by the amount of arc which can be drawn with a lead pencil.

   Caution - a bad burn will result if the antenna post is touched with a finger. Keep fingers on the wood of the pencil. DO NOT use a metal cased pencil.

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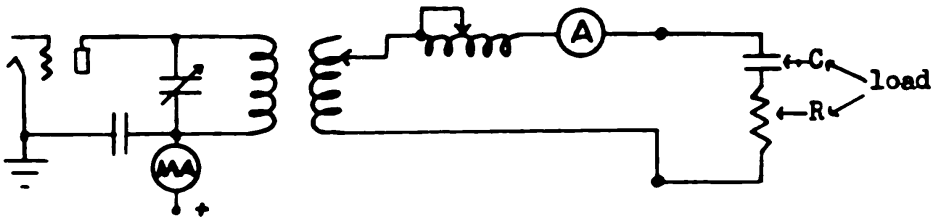
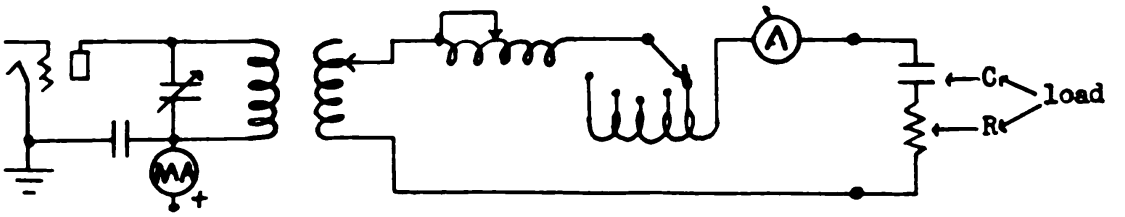
CLASSROOM PROBLEMS

1. In the following circuit, the load has a large amount of capacity (small capacitive reactance). Should the tuning inductor have large or small inductance? Where would a short-circuiting tap be placed to obtain this inductance?



ANS: _____

2. In the following circuit, the load has a small amount of capacity (large capacitive reactance). Explain how to adjust the circuit to resonance.

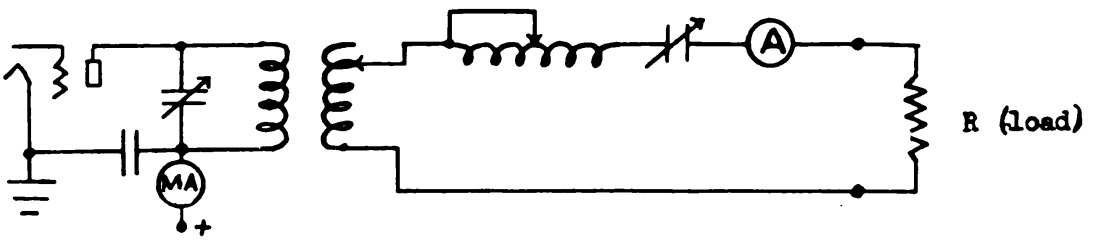


ANS: _____

_____

_____

3. In the following circuit, the load has low resistance, with negligible capacity or inductance. Explain how to adjust the circuit to resonance.



ANS: _____

_____

_____

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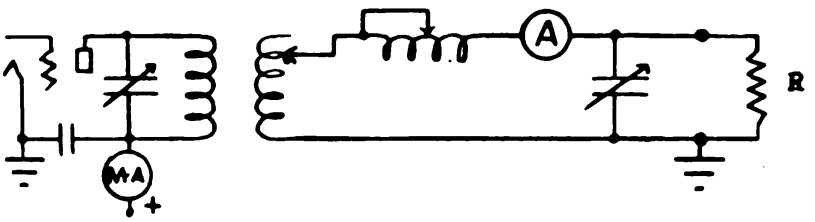
4. Assume the following output circuit is kept resonant at all times.



What adjustment will place a lower limit on the amount of circulating current in the output coupling unit?

ANS:_____

_____

5. What adjustment above will decrease the RF voltage across the load?

ANS:_____

_____

6. Which unit above is adjusted to maintain resonance after the adjustment of another unit is changed?

ANS:_____

7. What precaution must always be observed in connection with the plate tank circuit?

ANS:_____

_____

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RADIO PRINCIPLES

HOMEWORK

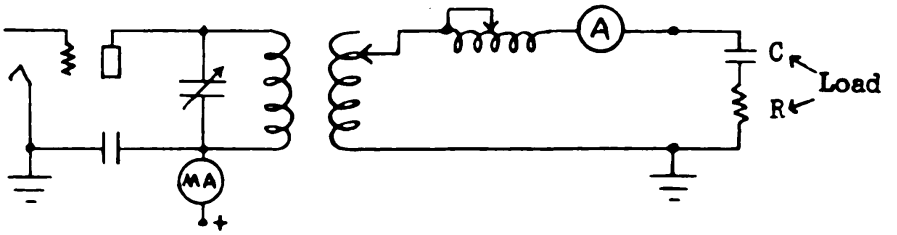
. An output coupling network is properly adjusted for operation on 6,000 KC. Will this adjustment be changed very much if the transmitter frequency is shifted to 5990 KC? To 7,000 KC?

ANS:_____

. What final adjustment is always made on a transmitter after adjusting the output coupling network?

ANS:_____

. In the following circuit, the output network has been properly adjusted for operation at 3,000 KC. What procedure would be required to readjust it for operation at a slightly lower frequency?

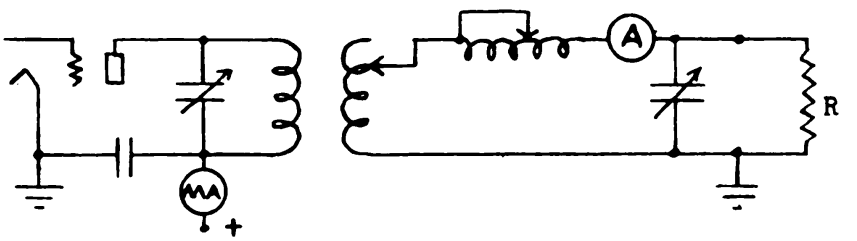


ANS:_____

. Refer to diagram in Question 3. What can be done if the tuning inductor does not have sufficient inductance for resonance?

ANS:_____

. In the following circuit, how could you determine if high RF voltage was being supplied to the load?



ANS:_____

Refer to diagram in Question 5. Describe the method of increasing the amount of RF voltage supplied across the load resistor.

ANS:_____

_____

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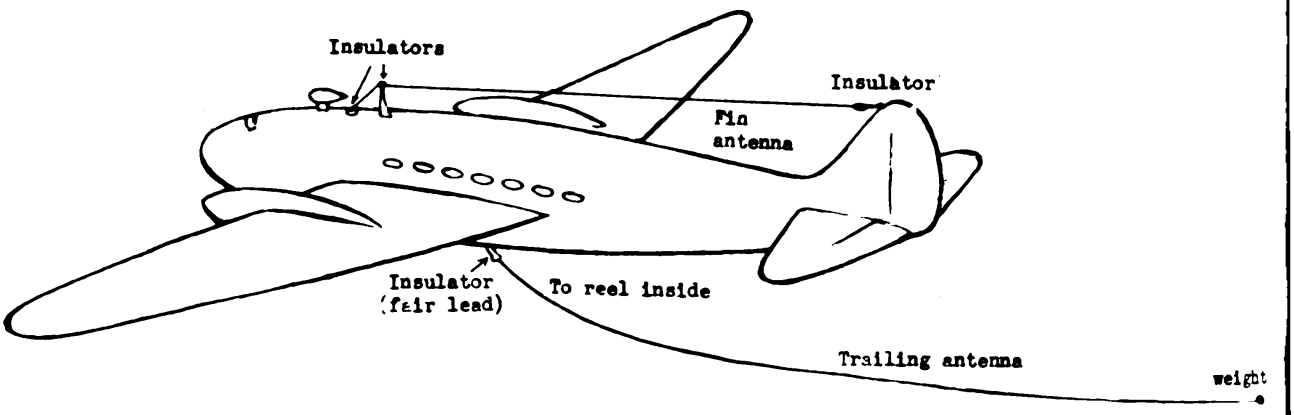
AIRCRAFT TRANSMITTER ANTENNAS



Large aircraft are equipped with several radio antennas. The ones most commonly used for radio transmitters are the fin antenna and the trailing antenna.

The fin antenna is of fixed length. The wire connecting the antenna to the transmitter is called the "lead-in". It is run from near the forward end of the antenna, through an insulator to keep it from short-circuiting to the plane structure, to the trarsmitter in the forward part of the plane.

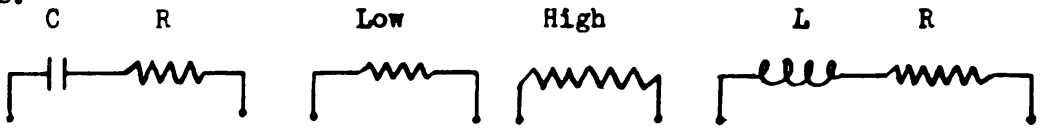
The trailing wire antenna is wound on a reel so its length may be adjusted. It must be wound in before landing. The length of the antenna determines its impedance. Tuning may be accomplished by varying antenna length. Low frequencies require long antennas. Common lengths used are: 250' for 500 KC or lower, 100' for 3 megacycles, 50' for 6 megacycles.

Short fixed antennas have low resistance at low frequencies. At high frequencies, the resistance will vary over wide ranges depending upon the particular frequencies. Output tuning must be readjusted when frequency is changed. Sometimes a small change in frequency will greatly change the antenna resistance.

EXAMPLE PROBLEMS

1. Show the three types of load which may be the equivalent of an antenna depending upon the frequency used.

ANS:



Capacitive Resistive Inductive

2. What precautions should be observed in handling trailing antennas?

ANS: Care must always be taken to exert a steady pressure on the handle of the reel. The reel locks in position automatically when the handle is released. If the antenna is being reeled out rapidly, sudden locking of the reel will cause severe strain on both the reel and the wire. The weight may swing up and damage the plane structure or the wire may break. Special care should be exercised at speeds above 150 M.P.H.

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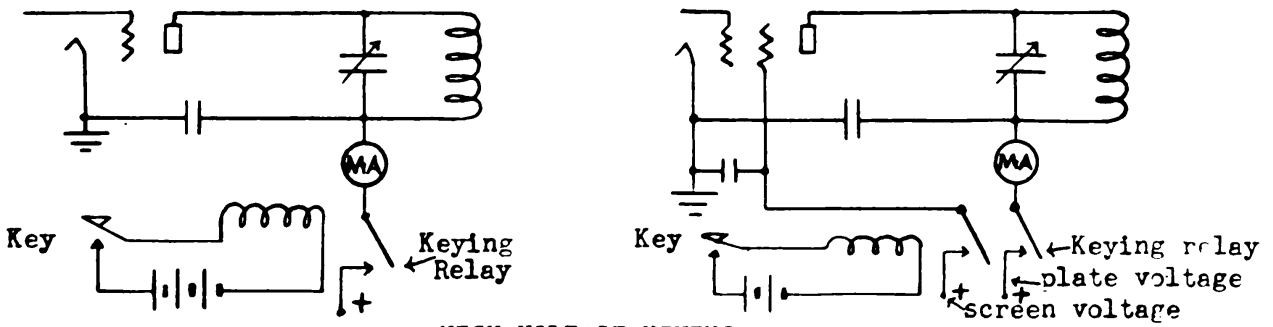
RADIO PRINCIPLES

CLASSROOM PROBLEM

1. The same antenna is usually used for both receiving and transmitting. Draw a diagram of a relay arranged to shift the antenna back and forth from receiver to transmitter. Such a relay is often called an "antenna change-over" relay.

ANS:

TRANSMITTER KEYING

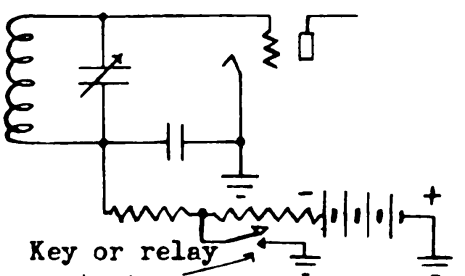


HIGH VOLTAGE KEYING

Radiotelegraph transmitters require a means of turning the output on and off by means of a telegraph key. This is called "keying" the transmitter.

One means of keying is to insert a relay in the high voltage plate supply lead. When the key is closed, the relay closes the DC circuit.

When a screen grid tube is keyed by this means, an additional contact must be provided on the relay to remove the screen voltage at the same time the plate voltage is removed. Otherwise, the positive voltage on the screen will cause excessive screen current during the time there is no voltage on the plate.



BLOCKED GRID KEYING

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Another method of keying is to provide a high negative bias on the grid sufficient to cut off the flow of plate current. When the key is closed, it short-circuits this fixed bias, leaving only grid leak bias on the tube. The tube then operates normally until the key is opened, once more cutting off the plate current.

A resistor must be used in series with the bias battery so the battery will not be directly short-circuited when the key is closed.

This is called "blocked grid" keying. It is often used to key oscillator tubes.

EXAMPLE PROBLEM

1. Why is it necessary to always use a relay when keying high voltages?

   ANS: Use of a relay makes it possible to use only a few volts on the keying lines. This means safety to the operator as well as making it unnecessary to run heavily insulated high voltage leads to the key.

CLASSROOM PROBLEMS

1. The oscillator tube of a transmitter is keyed. What types of bias may be used on the amplifier tube following it to prevent this tube from overheating while the key is open?

   ANS:_____

2. A transmitter is keyed by blocked grid keying. Is plate voltage still on the transmitter circuits, even when the key is open?

   ANS:_____

3. Radiotelephone transmitters are often controlled by simply turning on and off the low voltage DC supplying the tube filaments and high voltage dynamotor. Why is this advantageous for a radiotelephone transmitter? Why would it be an unsatisfactory means of keying a radiotelegraph transmitter?

   ANS:_____

   _____

   _____

4. The antenna change-over relay is often connected to operate simultaneously with the keying relay. What is the advantage of this?

   ANS:_____

   _____

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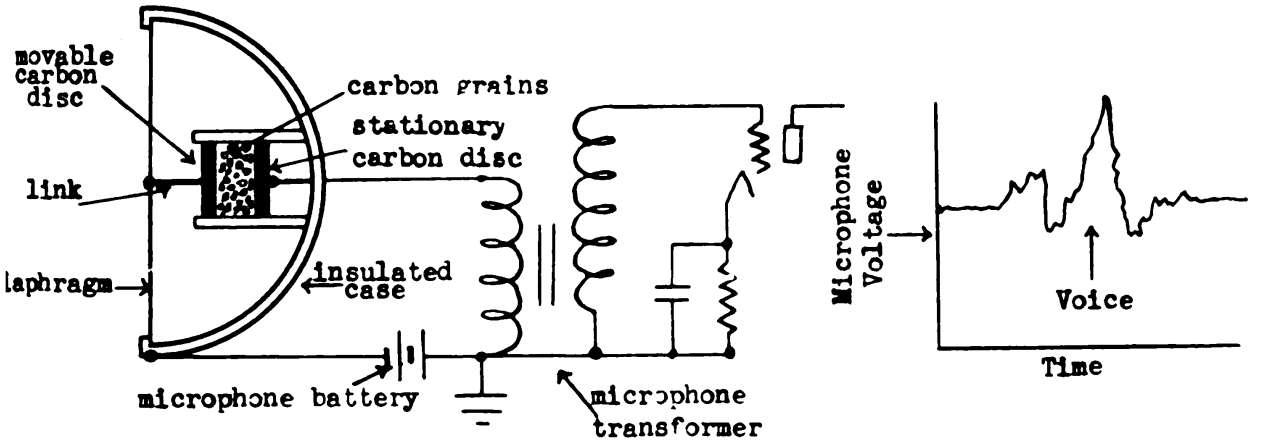
CARBON MICROPHONES



Sound produces a variation in pressure on the diaphragm. This causes the diaphragm to bend in and out. Pressure on the carbon granules alternately increases and decreases.

When the granules are packed more tightly, their resistance decreases and a larger current flows through the microphone. When the granules are packed loosely, their resistance is increased and less current flows through the microphone.

The changes in microphone current produce a changing field in the windings of the microphone transformer.

The changing field in the primary of the microphone transformer causes an alternating voltage to be set up across the secondary of the transformer. This voltage changes in accordance with the frequency and strength of the original sound. A varying voltage is therefore placed on the tube grid.

COMMON USES

Carbon microphones are used almost exclusively for aircraft, since they are sturdy and provide a much larger amount of voltage than most other types of microphone.

A switch is usually included in the case of the microphone so the battery circuit will be closed only when actually using the microphone. An additional contact may be provided to turn on the transmitter at the same time.

EXAMPLE PROBLEMS

1. What is the cause of the slight hissing sound produced by a carbon microphone which is heard during otherwise silent periods?

   ANS: The carbon granules are heated slightly by the passage of the battery current through them. This heating causes mild expansion which constantly causes small motions of the grains. The resulting variation in resistance gives a slight hiss even though the diaphragm is not being moved.

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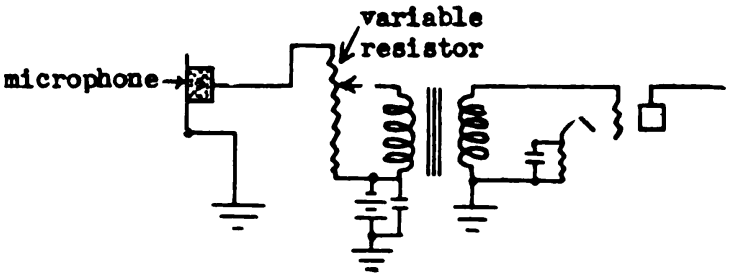
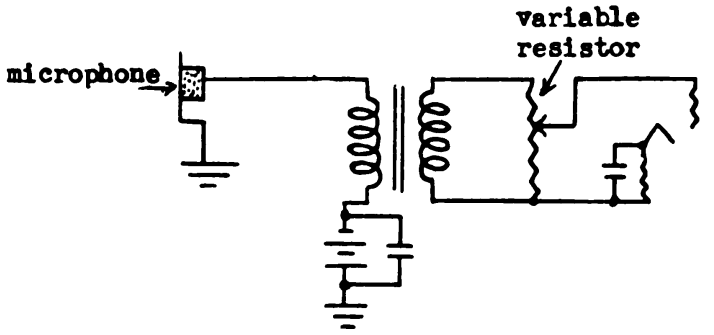
2. How may the output of the microphone transformer be adjusted to give the proper voltage for the grid?

ANS:



For maximum output, the movable contact is moved to the top of the resistor. Moving the contact down the resistor reduces the voltage across the transformer primary. This reduces the voltage supplied to the grid.



Another arrangement often used places the resistor across the secondary of the microphone transformer. The grid is connected to a movable contact. Grid driving voltage is maximum when the contact is at the top of the resistor and zero when the contact is moved to the bottom.

In either case, a by-pass condenser is placed across the microphone battery. This connects the primary winding to ground as far as RF is concerned, also preventing voltage from the RF circuits being fed into the low frequency speech circuits.

CLASSROOM PROBLEMS

1. What is the effect on microphone operation if the carbon grains become packed too tightly?

ANS:_____

2. What is the effect on microphone operation if the carbon grains are packed too loosely?

ANS:_____

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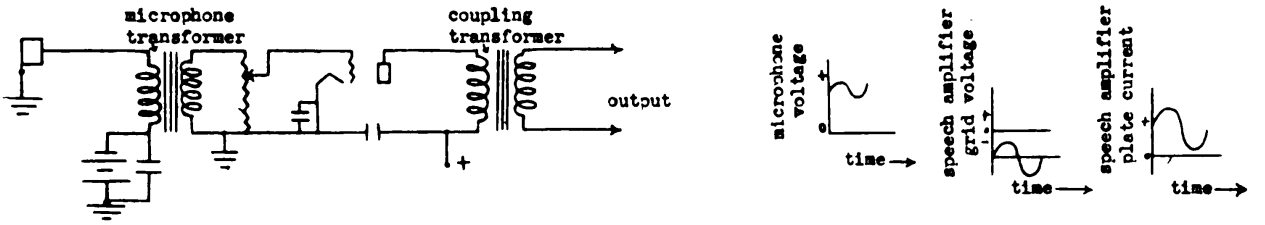
SPEECH AMPLIFIERS



SPEECH AMPLIFIERS

The large voltage variation produced by a carbon microphone makes it possible to secure an audio (voice) frequency output of several watts from a single speech amplifier tube. This is sufficient to drive a class B amplifier.

The speech amplifier tube is used to drive the grids of succeeding tubes.

A microphone which causes very small variation in voltage must be followed by a pentode or beam power tube used as a voltage amplifier. This will provide sufficient audio frequency ("AF") voltage to drive the grid of the speech amplifier. Such an amplifier is called a "pre-amplifier".

EXAMPLE PROBLEM

1. What is the difference between a voltage amplifier and a power amplifier?

   ANS: A voltage amplifier produces large increases in voltage for each such amplifier used. It produces little power as a rule so it usually drives a Class A tube.

   A power amplifier produces large increases in power. It generally requires wider variations in its grid voltage than does a voltage amplifier. It will require some power to drive it if Class B or Class C.

CLASSROOM PROBLEMS

1. Large amplification is desired. What is the difference in the resistance of the load for voltage amplifier and for a power amplifier?

   ANS:_____

   _____

2. Draw a diagram of a pentode preamplifier tube followed by a triode speech amplifier tube.

   ANS:

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HOMEWORK

1. The maximum length of your trailing antenna is 250 feet. You desire to transmit on 300 KC. What length of wire should be reeled out? Is sufficient wire available?

   ANS:_____

2. How would the operator compensate when the trailing wire antenna is too short (at its full length) for the frequency to be used?

   ANS:_____

3. When the fixed antenna of an aircraft is 60 feet long, why is it unnecessary to make use of the trailing antenna above 5 mc?

   ANS:_____

4. Screen voltage for a tube can be obtained through a dropping resistor in series with the high voltage plate supply. Draw a diagram showing how the high voltage supply for such a tube can be keyed by a relay having only one pair of contacts.

   ANS:

5. The variable resistor controlling the amount of grid driving voltage of a speech amplifier tube is the "gain" control. What is the effect on the speech amplifier output when the gain control is set for low grid driving voltage? For high grid driving voltage?

   ANS:_____

6. Why is a pre-amplifier unnecessary when a carbon microphone is used?

   ANS:_____

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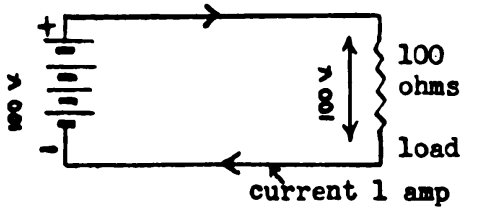
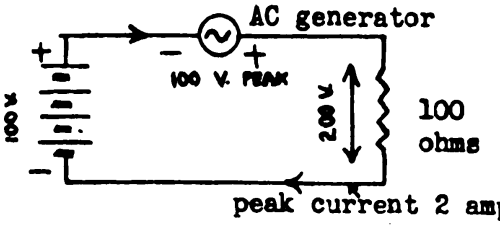
MODULATION

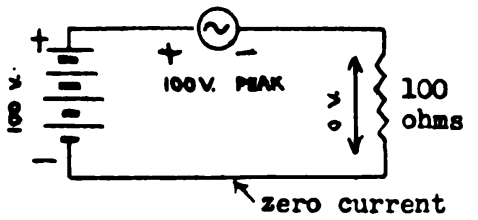


A 100 volt battery will force a current of 1 ampere through a 100 ohm load resistor. The resistor dissipates 100 watts, which is supplied by the battery.

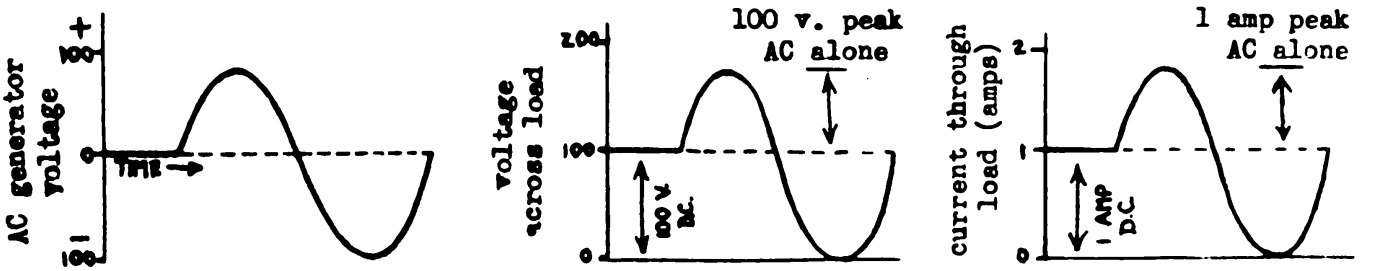


An AC generator is connected in the circuit. The voltage across the load resistor (and the resulting current through it) is modified by the changing voltage of the AC generator. This process is called "modulation".

At the instant the generator reaches peak positive voltage, the total voltage across the load is 200 volts. Load current is 2 amperes. Power is 400 watts.



At the instant the generator reaches peak negative voltage, total voltage across the load is zero. Load current is zero. Power is zero.



The peak voltage of the AC generator alone is 100 volts. Its effective (RMS) voltage is $\frac{100}{\sqrt{2}}$ volts.

The peak current with the AC generator alone is 1 ampere. RMS value is $\frac{1}{\sqrt{2}}$ amps.

Power furnished by the AC generator is: $\frac{100}{\sqrt{2}} \times \frac{1}{\sqrt{2}} = 50$ watts.

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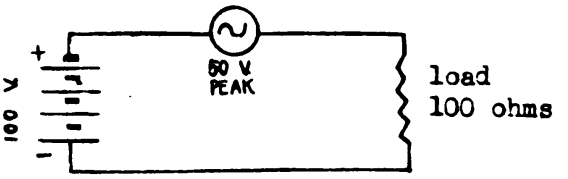
The battery alone delivers 100 watts. The total power both AC and DC, delivered to the load resistor is: $50 + 100 = 150$ watts.

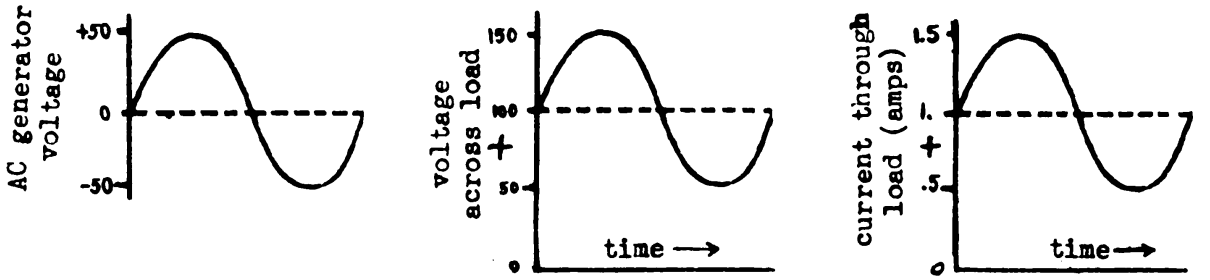
The condition where load voltage is varied from zero to twice its DC value is called "100% modulation". The AC generator causing this modulation is the "modulator".

EXAMPLE PROBLEMS

1. Illustrate an example of 50% modulation.

ANS:





For generator alone, RMS voltage = $\frac{50}{\sqrt{2}}$; RMS current = $\frac{.5}{\sqrt{2}}$; Power = $\frac{50}{\sqrt{2}} \times \frac{.5}{\sqrt{2}} = 13$ w.

For the battery alone, Voltage = 100; Current = 1 amp.; Power = $1 \times 100 = 100$ w.

Total modulated power delivered to the load = $13 + 100 = 113$ watts.

2. What is the effective value of current through the load at 100% modulation?

ANS: $W = I^2R \quad I^2 = \frac{W}{R} = \frac{150}{100} = 1.5 \quad I = 1.22$ or 22% increase.

3. Will a DC ammeter in the battery current change with modulation?

ANS: No, the average DC current is constant.

CLASSROOM PROBLEMS

1. What is the effective value of current through the load at 50% modulation?

ANS:_____

2. What per cent above the DC reading will the current increase when 50% modulation is applied?

ANS:_____

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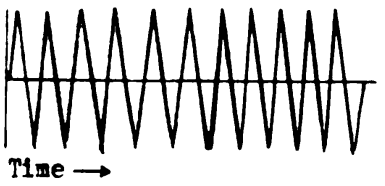
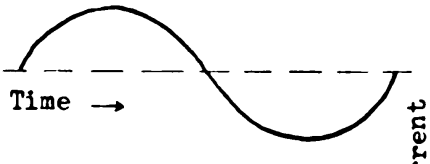
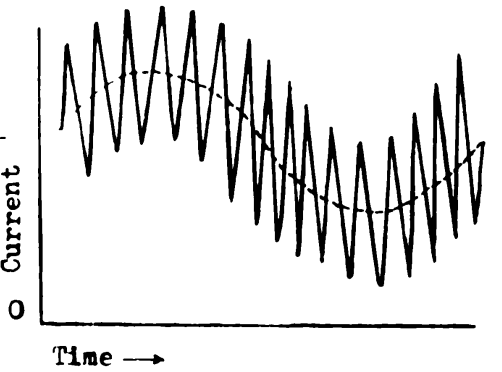
MODULATION OF R.F. POWER
(Class "A" R.F. amplifier)



RF PLATE OR GRID VOLTAGE



AF GRID OR PLATE VOLTAGE



RESULTING PLATE CURRENT

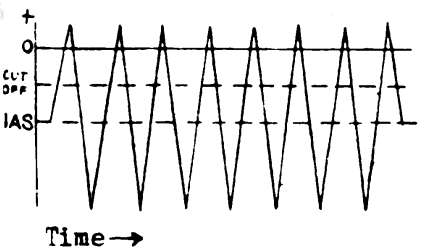
The current at the plate of a Class A amplifier tube varies directly with variations in grid voltage. This variation is shown at the left for the RF driving voltage.

An audio frequency voltage can also be placed on either the grid or the plate. The two voltages will produce the resulting plate current shown at the right.

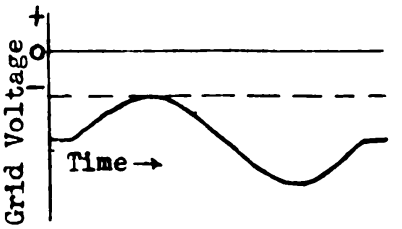
The RF portion of the plate voltage is still varying over the same range as before the audio frequency was added. RF power output is still the same.

A Class A amplifier is not suitable for modulation whether the AF voltage is added on the grid or the plate as the audio frequency does not change the power output.

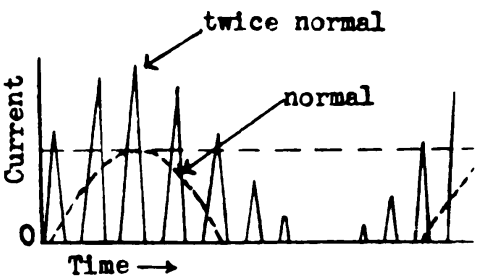
GRID MODULATED AMPLIFIER



RF GRID VOLTAGE



AF GRID VOLTAGE



RESULTING PLATE CURRENT

The current at the plate of a Class B amplifier tube varies from zero to maximum in accordance with the top of the positive halves of the cycle of grid driving voltage.

For grid bias modulation, the bias voltage is about twice that used for normal Class B service. To distinguish this amplifier, it is called a grid bias modulated amplifier.

When an AF grid voltage is added to the RF grid driving voltage, the plate current varies from zero to TWICE the value reached with only the RF grid voltage.

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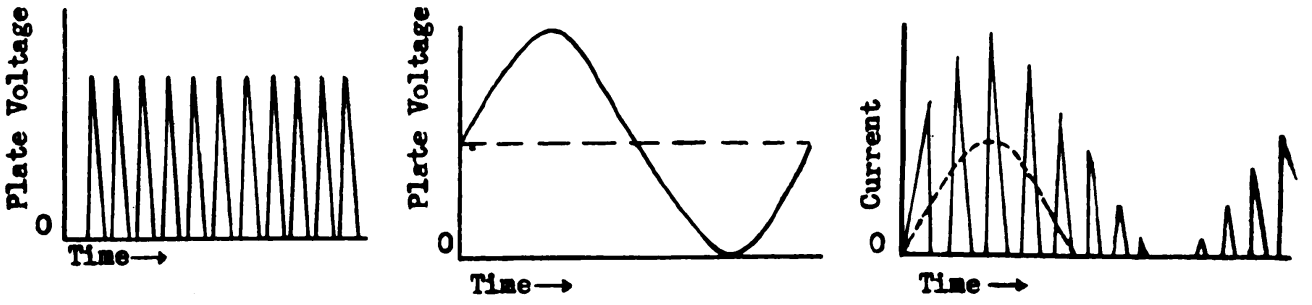
The RF power output, therefore, varies from zero to a PEAK OF FOUR TIMES the value reached with only the RF grid voltage. This is the condition of 100% modulation.

CLASS "C" MODULATED AMPLIFIER



RF PLATE VOLTAGE AF PLATE VOLTAGE RESULTING PLATE CURRENT

The RF plate current of a Class C amplifier cannot be increased by increasing grid voltage. Grid drive is so large that additional drive voltage will not increase peak plate current further.

However, if the plate voltage is increased, RF current peaks will become higher.

When the DC plate voltage is varied from zero to twice its normal value, RF plate current varies from zero to twice normal. RF output power varies from ZERO TO A PEAK OF FOUR TIMES NORMAL POWER. This is the condition of 100% modulation.

The RF output of a Class C amplifier can be modulated 100% by adding to the normal plate voltage an AF voltage having a peak value equal to the normal DC voltage.

EXAMPLE PROBLEM

1. A grid modulated RF amplifier is modulated by adding AF voltage to the RF grid driving voltage. What is the effect on the percentage of modulation if the peak of the AF voltage is low?

   ANS: Peak plate current will not increase to twice the unmodulated value. Modulation will be less than 100%.

CLASSROOM PROBLEM

1. A Class C RF amplifier is modulated by adding AF voltage to the DC plate voltage. What is the effect on the percentage of modulation if the peak of the AF voltage is lower than the normal DC plate voltage?

   ANS:_____

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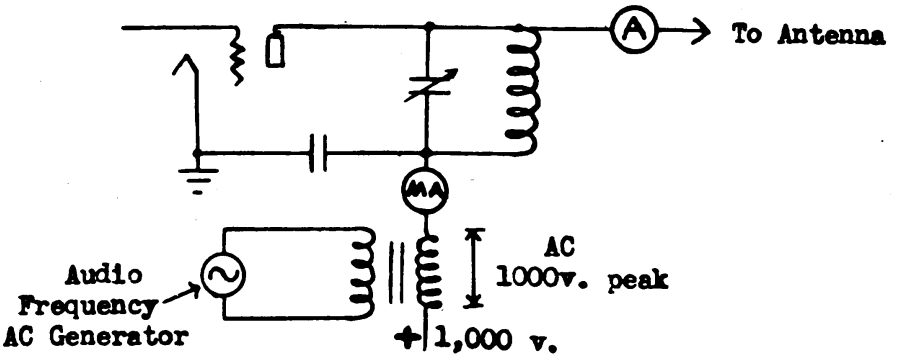
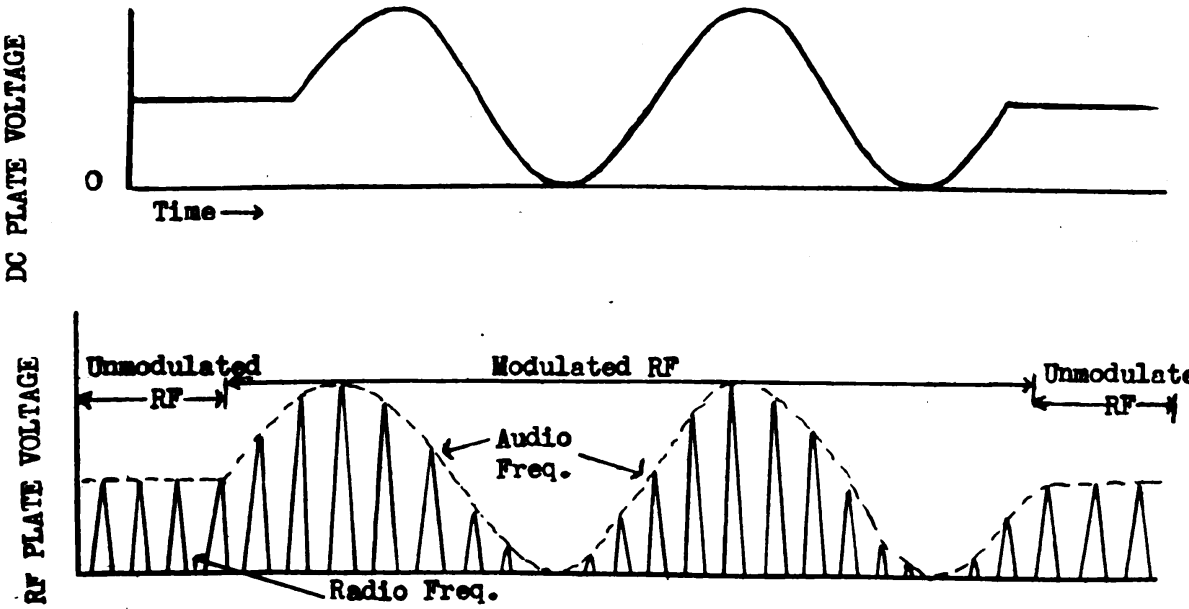
PLATE MODULATION
(Class C RF amplifier)



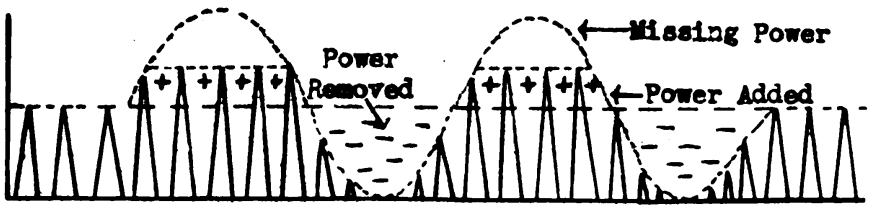
The tube plate current is varied from zero to twice its normal DC value by means of the AC in series with it.

The RF power in the plate circuit is varied, at audio frequency, between zero and four times normal DC value. This the condition of 100% modulation.



The DC plate voltage is varied by the addition of audio frequency voltage. This changes the RF voltage as shown above.

100% modulation will cause the antenna load current to increase 22% above its unmodulated value.



When a heavy load is placed on the plate tank, the tube is no longer able to deliver the necessary high RF current peaks.

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With 100% modulation, the antenna current of an over-loaded RF amplifier will not increase 22%. It may increase slightly or even decrease. This is because the modulation is removing some RF power on the negative half of the AF cycle and NOT ADDING any appreciable power on the positive half of the cycle.

This condition is frequently encountered in the adjustment of aircraft transmitters.

IF THE ANTENNA CURRENT DOES NOT INCREASE ABOUT TWENTY PER CENT ON HEAVY MODULATION, ALWAYS REDUCE THE COUPLING BETWEEN THE TRANSMITTER AND THE ANTENNA.

On the other hand, if the antenna current rises much more than 22%, coupling between the transmitter and antenna should be increased. A large increase in antenna current with modulation indicates that the antenna is not taking enough power from the modulated tube.

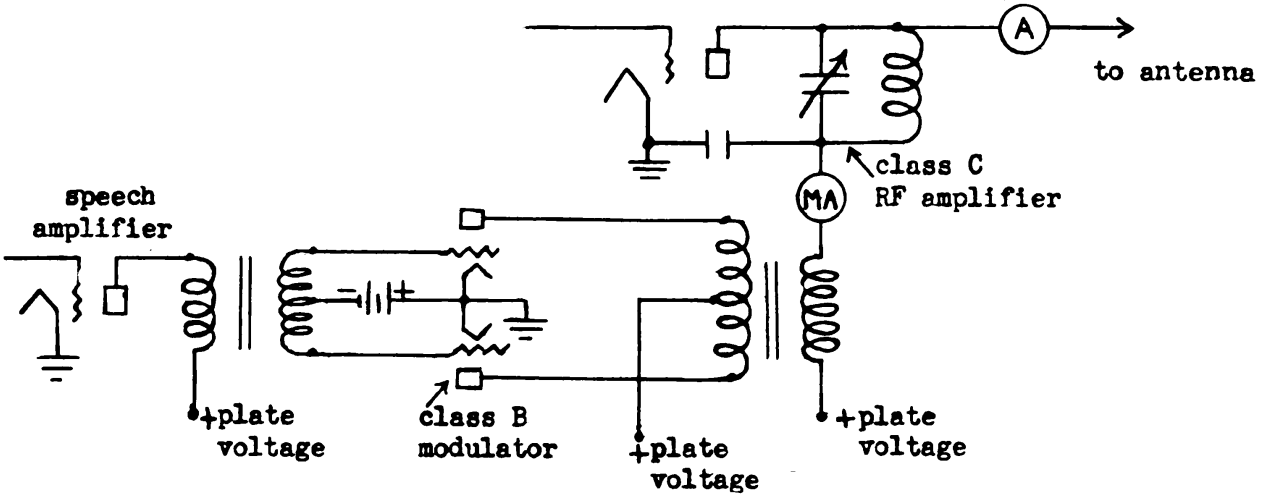

Plate modulation is usually accomplished with two audio frequency amplifier tubes operated in Class B. These are the "modulator" tubes. They receive their grid drive from the speech amplifier tube.

The DC plate current of the Class C amplifier should remain steady with modulation. Actually the DC plate voltage source is affected during modulation as some variation on AC plate current is found.

EXAMPLE PROBLEMS

1. Can a Class A amplifier be used to supply audio frequency power for plate modulation?

   ANS: Yes. However, the efficiency of a Class A amplifier is much lower than for Class B. This makes Class B more economical when modulating an RF amplifier which requires a very large amount of AF power; especially where weight is at a premium.

2. Will the DC plate current of the Class B modulator vary during modulation?

   ANS: Yes. A Class B modulator is biased near cut-off so there is little plate current until grid excitation is applied.

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CLASSROOM PROBLEM

1. A properly adjusted radiotelephone transmitter will cause antenna current to increase approximately 20% when 100% modulated by a steady tone. Why will the increase in current average considerably less when the transmitter is modulated by normal speech?

ANS:_____

_____

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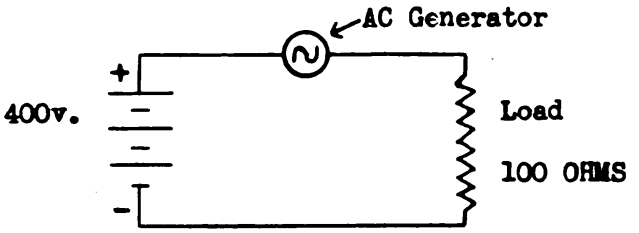
HOMEWORK

1. In the following circuit, what peak AC generator voltage is required for 100% modulation?



ANS:_____

2. Refer to the diagram in Question 1. At 100% modulation, what will be the reading of a DC ammeter connected in series with the load? An AC ammeter?

ANS:_____

3. Refer to the diagram in Question 1. At 50% modulation, what will be the reading of a DC ammeter connected in series with the load? An AC ammeter?

ANS:_____

4. What is the effect on the plate current of a grid modulated amplifier if the AF grid voltage has too high a peak value?

ANS:_____

5. What is the effect on the plate current of a Class C modulated amplifier if the AF plate voltage has a peak of more than twice the steady DC plate voltage?

ANS:_____

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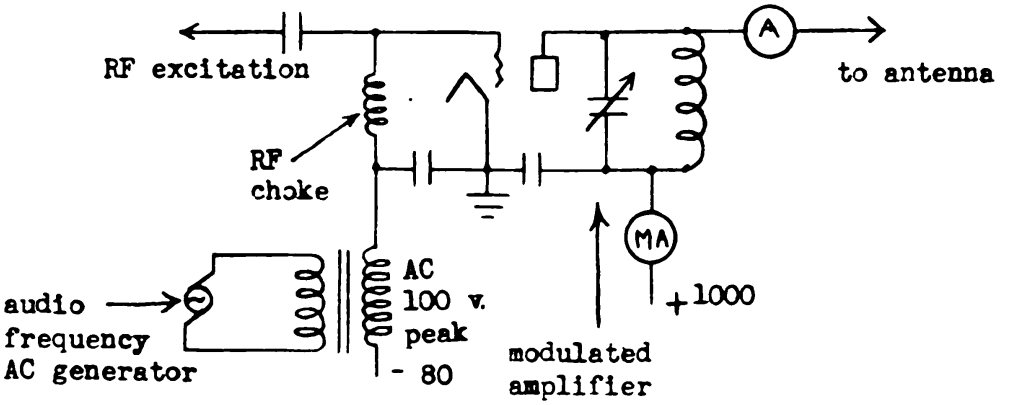
GRID BIAS MODULATION

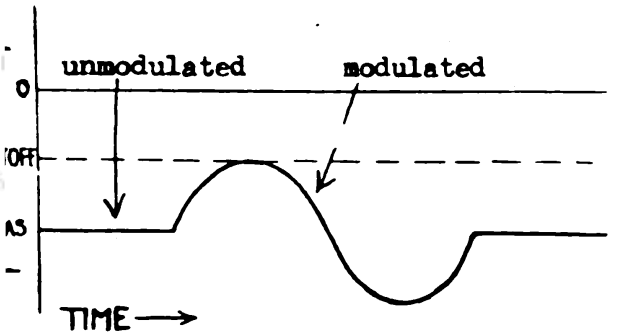


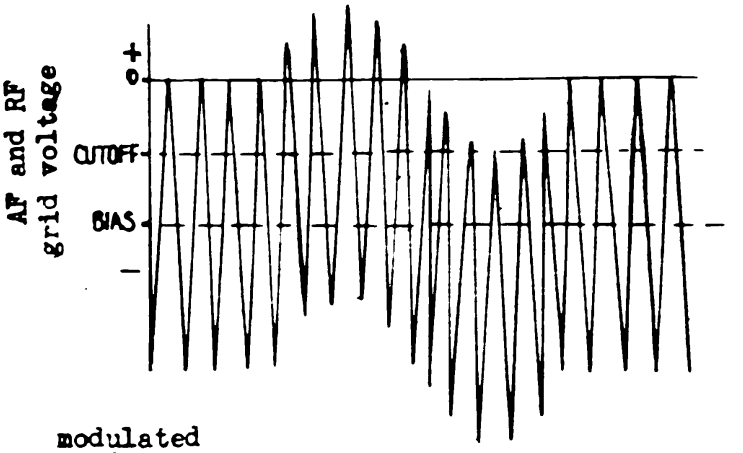
A source of AC connected in series with the DC grid bias voltage of a vacuum tube.

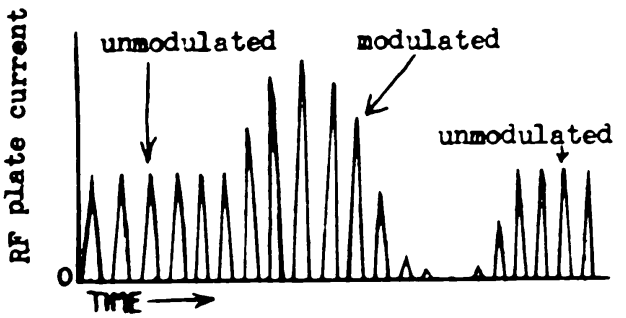
As the AC voltage varies, the tube bias voltage is varied from a negative value well beyond cutoff to a positive value which allows considerable plate current to flow.

These variations in grid bias voltage cause plate current to vary from zero to twice its value with steady bias.

The RF power from the plate circuit is varied at audio frequency between zero and a peak of four times normal DC value. This is the condition of 100% modulation.







The DC grid bias voltage is varied by the addition of audio frequency voltage. This changes the RF plate current as shown.

100% modulation will cause the antenna (load) current to increase to 22% above its unmodulated value.

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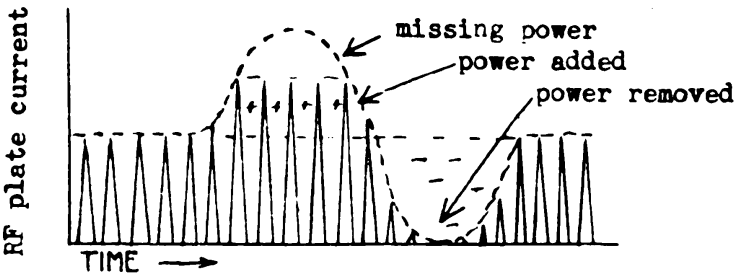

When a heavy load is placed on the plate tank, the tube is no longer able to deliver the necessary high RF current peaks.

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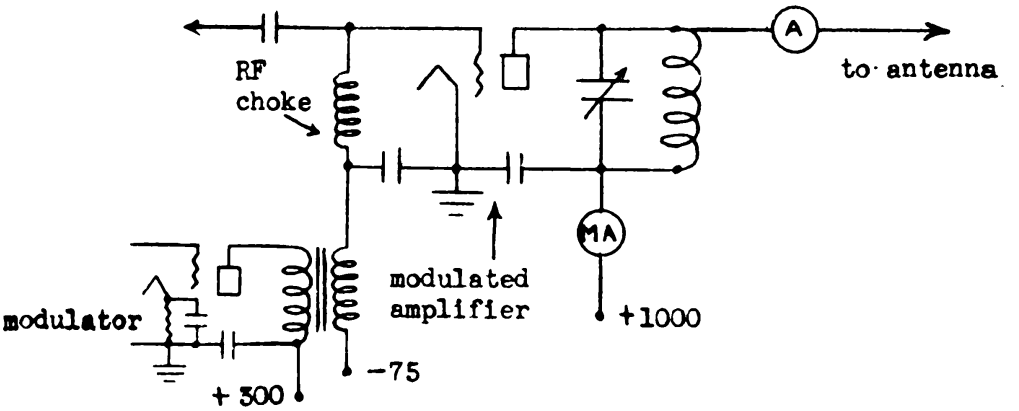

Grid modulation is usually accomplished with a single audio frequency amplifier tube operated in Class A. This is called the "modulator" tube.

The high output of a carbon microphone permits the use of a single tube acting as both speech amplifier and modulator. Very little audio frequency power is required for modulation. The purpose of the modulator is to vary the grid bias voltage at audio frequency.

The unmodulated RF output is limited to one fourth the maximum obtainable output. This is because the modulated amplifier must be able to supply peaks of four times the unmodulated power.

The DC plate current should remain steady during modulation. Slight variations in DC plate supply voltage will cause some variations.

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EXAMPLE PROBLEMS

1. The unmodulated RF output of a radiotelephone transmitter is called the "carrier". Will the carrier power of a grid modulated RF amplifier be as great as that of a Class C plate modulated RF amplifier?

   ANS: The carrier power of a grid modulated amplifier is only about one-fourth that of the same tube plate modulated. With plate modulation, additional voltage is supplied to the plate by the modulator to enable the RF output to reach peaks of four times its unmodulated power.

2. Describe the method of adjusting a grid modulated RF amplifier.

   ANS: Set fixed grid bias at about cutoff value. Adjust RF drive to the point where increased drive gives no increase in plate and RF output current. Read antenna current (making sure final plate tank is set at resonance). Increase negative bias until antenna current drops to one-half its maximum value. This gives a carrier power of one-fourth the maximum power available.

CLASSROOM PROBLEMS

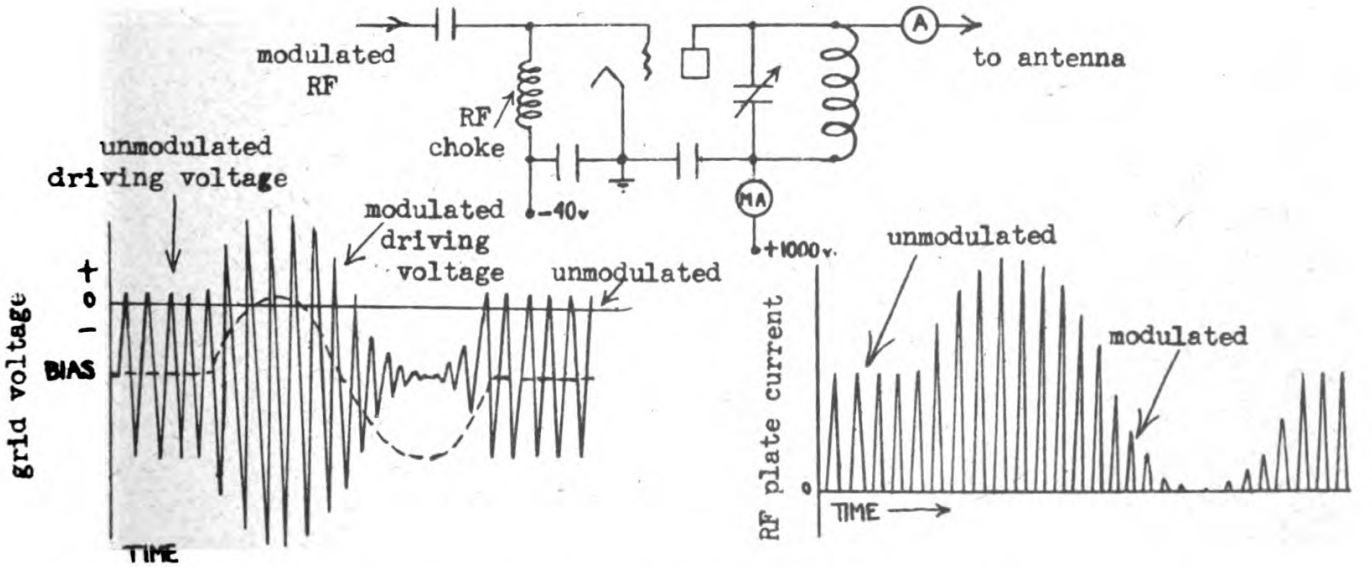
1. What is the advantage of grid modulation over plate modulation?

   ANS:_____

2. What is the advantage of plate modulation over grid modulation?

   ANS:_____

CLASS B LINEAR AMPLIFIERS
(Used to amplify modulated RF power)



The bias on the RF amplifier tube is about cutoff value (Class B operation).

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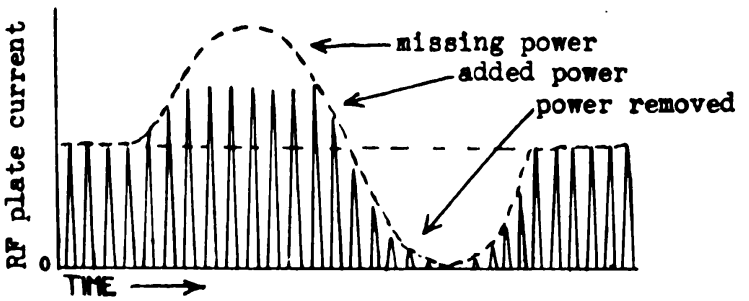
The RF grid drive is obtained from a tube which is grid or plate modulated to produce modulated RF drive for the Class B amplifier.

When the RF grid drive is unmodulated, RF plate current will flow in accordance with the positive halves of the driving voltage cycle.

When the RF grid drive is modulated, RF plate current will reach peaks of twice as much current as when unmodulated. Plate RF power will vary from zero to a peak of four times the unmodulated value. This is the condition of 100% modulation. This is called a linear amplifier because the positive halves of the RF driving voltage are exactly reproduced in the plate current.



When a heavy load is placed on the plate tank, the tube is no longer able to deliver the necessary high RF voltage and current peaks.

With 100% modulation, the antenna current of an over-loaded RF amplifier will not increase 22%. It may increase slightly or even decrease. This is because the modulation is removing some RF power on the negative half of the audio frequency cycle and NOT ADDING any appreciable power on the positive half of the cycle.

This condition is frequently encountered in the adjustment of aircraft transmitters.

IF THE ANTENNA CURRENT DOES NOT INCREASE ABOUT TWENTY PER CENT ON HEAVY MODULATION, ALWAYS REDUCE THE COUPLING BETWEEN THE TRANSMITTER AND THE ANTENNA.

On the other hand, if the antenna current rises much more than 22%, coupling between the transmitter and antenna should be increased. A large increase in antenna current with modulation indicates that the antenna is not taking enough power from the modulated tube.

The unmodulated RF output of a Class B linear amplifier is limited to one fourth the maximum obtainable output. This is because the amplifier must be able to supply peaks of four times the unmodulated power.

The DC plate current should remain steady during modulations. Slight variations in DC plate supply voltage will cause some variations.

EXAMPLE PROBLEMS

1. How does the carrier power of a linear amplifier compare with that of a grid modulated amplifier? With a Class C plate modulated amplifier?

   ANS: The carrier power of a linear amplifier is about the same as that of a grid modulated amplifier. It is only about one-fourth that of the same tube when plate modulated.

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2. Describe the method of adjusting a linear RF amplifier.

ANS: Set fixed grid bias at about cutoff value. Adjust unmodulated RF drive to the point where increased drive just gives no added increase in plate and RF output current. Read antenna current (making sure final plate tank is set at resonance). Decrease RF drive until antenna current drops to one-half its maximum value. This gives a carrier power of one-fourth the maximum power available and is correct if the load is proper.

CLASSROOM PROBLEMS

1. A Class A amplifier will give faithful reproduction. Why is such an amplifier undesirable where any sizable RF power is to be handled?

ANS:_____

_____

2. Why is it impossible to use a Class C amplifier as a linear amplifier?

ANS:_____

_____

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RADIO PRINCIPLES

HOMEWORK

1. A certain tube is capable of delivering a carrier power of 200 watts when plate modulated. Approximately what carrier power can be obtained if the same tube is grid modulated?

   ANS:_____

2. Why does doubling the antenna current mean four times as much power is being supplied to the antenna?

   ANS:_____

3. Why can a tube be expected to deliver about the same carrier power with grid modulation as when it is used as a linear amplifier?

   ANS:_____

4. Why is the average antenna current of a radiotelephone transmitter higher with steady tone modulation than with voice modulation?

   ANS:_____

5. The unmodulated carrier of a radiotelephone transmitter is more than one-fourth of the peak obtainable output. What is the effect on the output when modulation is attempted?

   ANS:_____

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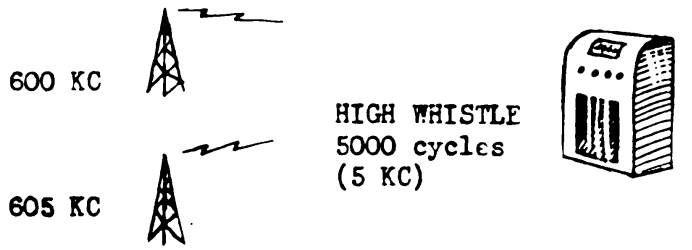
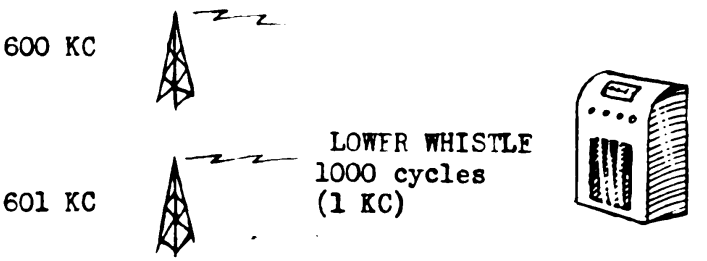
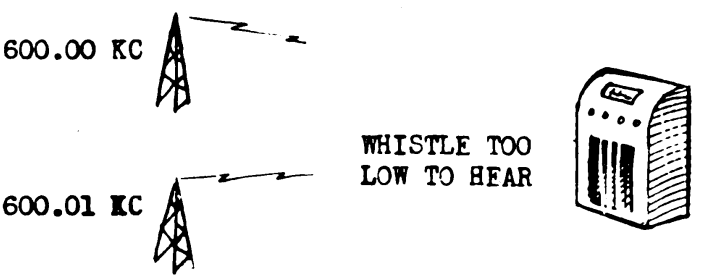
COMPARING FREQUENCIES







The whistle caused by two radio stations transmitting on near the same frequency is called a "beat note".

The frequency of beat note is equal to the difference in frequency between the two stations.

EXAMPLE PROBLEMS

1. One radio station transmits on 1490.0 KC and another on 1490.5 KC. Both stations are heard with equal strength. What beat note will be heard?

   ANS: Beat note frequency = Frequency difference

   Beat note = 1490.5 - 1490.0 = .5 KC or 500 cycles.

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2. A local radio station operates on 1490.0 KC. A station 2,000 miles away operates on 1490.5 KC. What beat note would be heard?

   ANS: Probably none. The signal from the distant station would not be loud enough to have much effect on a local station.

CLASSROOM PROBLEMS

1. One station operates on 600.0 KC and another station on 559.25 KC. What is the frequency of the beat note which will be heard?

   ANS: _____

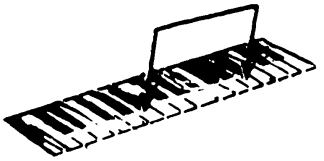
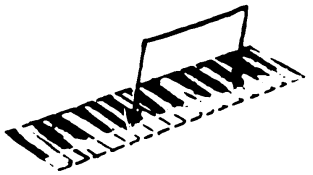
2. A high frequency broadcast station operates on 9.7005 MC. Another operates on 9.7010 MC. What is the frequency of the beat note?

   ANS: _____

3. Two stations operate on frequencies 15 cycles apart. Will a beat note be heard?

   ANS: _____

HARMONICS
(Whole multiples of a frequency)

	Frequency Produced (Fundamental)	Additional Frequencies Heard (Harmonics)		
		2nd harmonic	3rd harmonic	4th harmonic
	200 cycles	400 cycles	600 cycles	800 cycles, etc.
	101 cycles	202 cycles	303 cycles	404 cycles, etc.
	101 and 200 cycles	Second harmonic of 101 cycles = 202 cycles Fundamental of 200 cycles = 200 cycles Both notes <u>sound</u> close together (2 cycles apart)		
	101 and 200 cycles	Fourth harmonic of 101 cycles = 404 cycles Second harmonic of 200 cycles = 400 cycles Again, both <u>sound</u> close together (4 cycles apart)		

A harmonic is a whole multiple of the fundamental frequency. You do

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not hear just one note on a piano. You hear harmonics of that note too. The relationship of harmonic amounts makes it possible for you to tell the difference between a piano and an organ BOTH of which are sounding the same fundamental frequency.

Harmonics, as well as fundamentals, can be used to compare two frequencies.

EXAMPLE PROBLEMS

1. What is the fourth harmonic of a radio signal whose fundamental frequency is 225 KC?

   ANS: 4th harmonic = 4 x fundamental = 4 x 225 = 900 KC.

2. What beat note will be heard between signal "A" having a fundamental frequency of 1000 KC and the fourth harmonic of signal "B", which has a fundamental frequency of 249 KC?

   ANS: Frequency of signal "A" = 1000 KC

   4th harmonic signal "B" = 4 x 249 = 996 KC

   Beat note = 1000 - 996 = 4 KC or 4000 cycles

3. One station is at 250 KC. The frequency of a second station is slowly increased from 249 KC to 251 KC. What will happen to the beat note?

ANS: The beat note will gradually decrease from 1000 cycles until it becomes zero when the second signal is exactly 250 KC. This is known as "zero beat". When the frequency of the second signal is further increased, the beat note frequency will increase. When the frequency of the second signal reaches 251 KC, the beat note will be 1000 cycles.

CLASSROOM PROBLEMS

1. What is the third harmonic of a radio signal whose fundamental frequency is 2495.5 KC?

   ANS: _____

2. What beat note will be heard between signal "A", having a fundamental frequency of 9981.980 KC and the fourth harmonic of signal "B", which has a fundamental frequency of 2495.500 KC?

   ANS: _____

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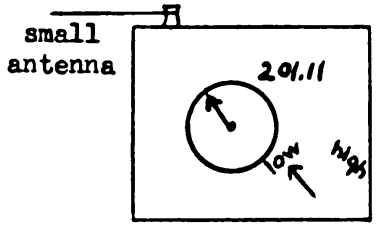
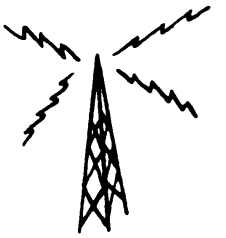
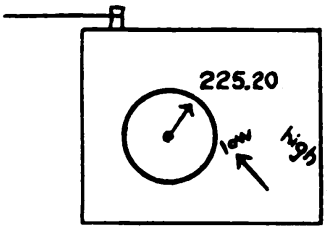
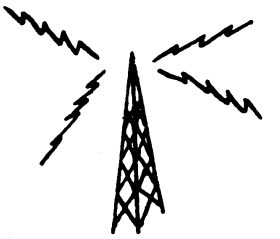
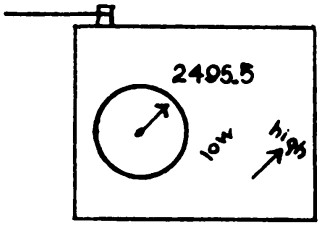
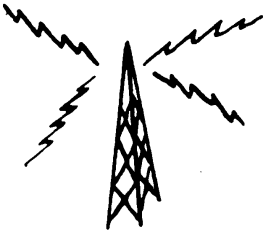
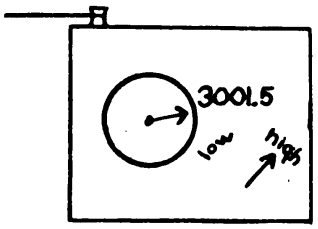
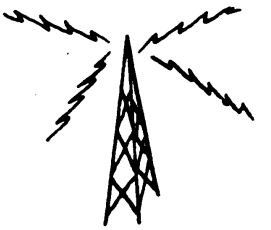
FREQUENCY INDICATORS
(Compare known and unknown frequencies)

Frequency Indicator (Also producing harmonics)	Indicated Frequency (Signals set to zero beat)	Radio Station (Freq. known approximately)
	Indicator = 201.11 KC Station is 201.11 KC	 Approx. 200 KC
	Indicator = 225.20 KC 2nd harmonic = 450.40 KC Station is 450.40 KC	 Approx. 450 KC
	Indicator = 2495.5 KC Station is 2495.5 KC	 Approx. 2500 KC
	Indicator = 3001.5 KC 2nd Harmonic = 6003.0 KC Station is 6003.0 KC	 Approx. 6000 KC

Frequency indicators are used widely. An oscillator, whose frequency is calibrated, is adjustable over a range of frequencies by rotating its dial.

The low frequency range covers 125 to 250 KC. The fundamental frequency and the second, fourth and eighth harmonics are used for comparison purposes. Thus, frequencies from 125 to 2000 KC may be covered on the "low" range.

The high frequency range covers 2,000 to 4,000 KC. The fundamental frequency and the second, fourth and fifth harmonics are used for comparison purposes. Thus, frequencies from 2,000 to 20,000 KC may be covered on the "high" range.

A small radio receiver is incorporated in the indicator. The signal from the oscillator is combined with the signal whose frequency is known only approximately. The oscillator frequency is adjusted for zero beat between the two

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frequencies. The frequency of the outside signal must be known approximately so there will be no doubt which harmonic of the oscillator is beating with it.

The process of combining two signals to cause a beat note is called "heterodyning". Thus, the indicator oscillator is called a "heterodyne" oscillator.

EXAMPLE PROBLEMS

1. Harmonic frequencies of a nearby transmitter will be easily audible in the receiver of the frequency indicator. Is there danger of setting the transmitter on a frequency which is exactly one-half or one-third of the desired frequency?

   ANS: Yes. This has been done by a careless operator. The calibrations on the transmitter dials are approximately correct. Care must be taken to set the transmitter according to these calibrations before using the frequency indicator to obtain a more exact setting. Also, use as short an antenna on the frequency indicator as possible. No antenna at all should be used when very near the transmitter.

2. An operator attempting to set his transmitter on 6,000 KC accidentally sets its second harmonic on this frequency. What will be the fundamental frequency? Will he be able to communicate with stations on 6,000 KC?

   ANS: The fundamental frequency of the transmitter will be 3000 KC. Normally only the fundamental frequency of a transmitter can be heard at any distance. The transmitter will not be heard by stations listening on 6,000 KC although he can hear the 6,000 KC harmonic on his own receiver. However, it will interfere with stations using 3,000 KC.

CLASSROOM PROBLEMS

1. What is the effect on the accuracy of indication if the frequency of the heterodyne oscillator is not set at exactly zero beat with the incoming signal?

   ANS:_____

   _____

2. What is the effect on the accuracy of indication if the wrong harmonic of the heterodyne oscillator is set to zero beat with the incoming signal?

   ANS:_____

   _____

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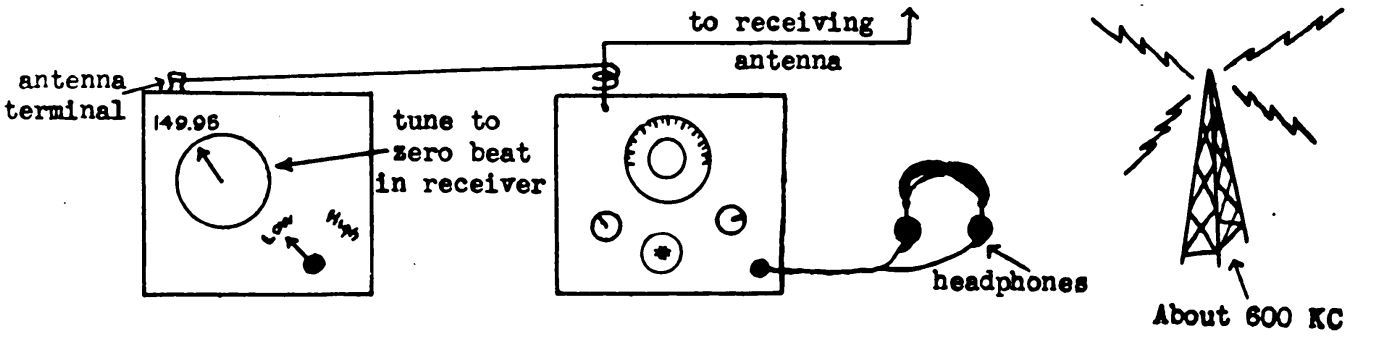
MEASURING FREQUENCY OF A DISTANT STATION



FREQUENCY INDICATOR RECEIVER DISTANT STATION

4th harmonic = 4 x 149.95 = 599.80 KC

Frequency of distant station = 599.80 KC

The frequency indicator is not sensitive enough to receive distant stations directly.

The distant station is tuned in on an ordinary radio receiver. The frequency indicator is coupled to the receiving antenna by a short piece of wire. No electrical connection is used; coupling is by capacity.

The frequency of the distant station is approximated by the dial setting of the receiver. The heterodyne oscillator is then adjusted to zero beat with the signal.

Frequencies of distant stations are indicated with a high degree of accuracy. They must be known approximately so the proper heterodyne oscillator harmonic will be chosen.

EXAMPLE PROBLEM

1. A distant station operates on approximately 400 KC. When adjusted to zero beat with the signal, the frequency of the heterodyne oscillator is 199.90 KC. Which harmonic of the oscillator is being used? What is the frequency of the distant station?

   ANS: The second harmonic of the heterodyne oscillator is being used. The frequency of the distant station = 2 x 199.90 = 399.80 KC

CLASSROOM PROBLEM

1. A distant station operates on approximately 10,000 KC. When adjusted to zero beat with the signal, the frequency of the heterodyne oscillator is 2505.50 KC. Which harmonic of the oscillator is being used? What is the frequency of the distant station?

   ANS: _____

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RADIO PRINCIPLES

HOMEWORK

1. When would you expect to hear the louder beat note, with two signals of about the same strength or with one very loud and one weak signal?

   ANS:_____

2. What beat note will be heard between signal "A", having a fundamental frequency of 5,000.00 KC, and the second harmonic of signal "B", having a fundamental frequency of 2499.99 KC?

   ANS:_____

3. When setting transmitter frequency by means of a frequency indicator, why should you avoid the use of too long an antenna on the indicator?

   ANS:_____

4. A distant station operates on approximately 6,000 KC. Which frequency range would you use on a frequency indicator when measuring the frequency of this station?

   ANS:_____

5. How useful is a frequency indicator if the receiver and transmitter are not already calibrated in approximate frequencies?

   ANS:_____

6. Can you tell which harmonic of a heterodyne oscillator you are hearing if no attention is paid to receiver calibration?

   ANS:_____

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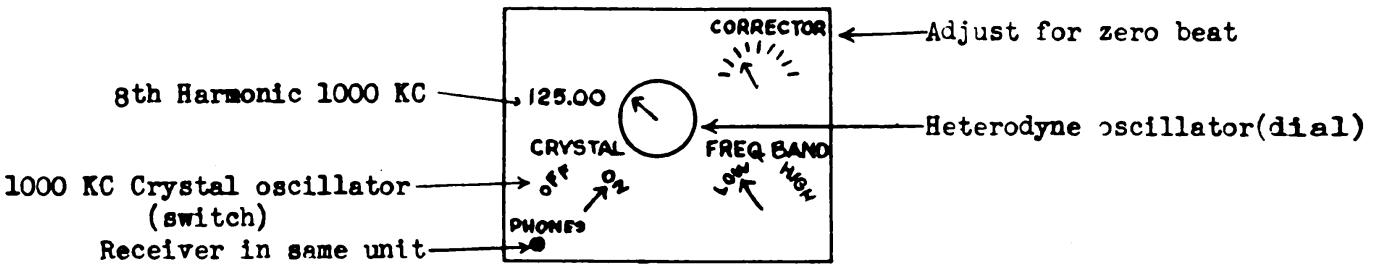
CORRECTION OF HETERODYNE OSCILLATOR CALIBRATION

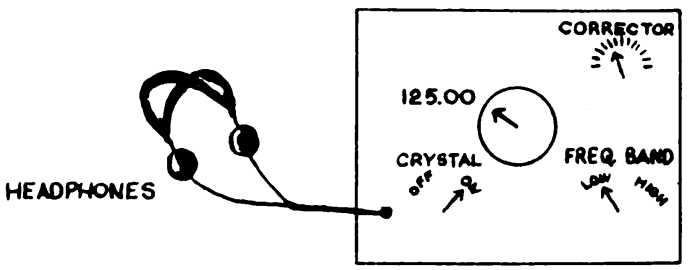


The dial calibration of a self-excited oscillator varies from time to time due to changes in temperature, humidity, voltage, etc. These changes slightly alter the resonant frequency of the circuit elements.

Dial calibrations may be corrected by comparing the heterodyne oscillator frequency with that of an oscillator having a known frequency. A second oscillator controlled by a crystal whose frequency is always within a few cycles of 1000 KC is incorporated in the frequency indicator.

The heterodyne oscillator is equipped with a "corrector". This is a small variable condenser connected in parallel with the larger condenser used to set the heterodyne oscillator.

Numerous points are available on both the "low" and "high" heterodyne oscillator ranges where exact comparisons can be made with the crystal oscillator frequency. Fundamental and harmonic frequencies of both oscillators are used to increase the number of check points.



FREQUENCY INDICATOR

The frequency indicator commonly used on aircraft has a heterodyne oscillator, crystal oscillator and receiver built in one unit. A dry battery power supply is contained in the case, forming a complete, readily portable instrument.

ADJUSTMENT OF CORRECTOR

Before making any frequency measurements, the heterodyne oscillator must first be corrected for the crystal check point nearest the frequency to be measured, after allowing it to warm up for a few minutes.

For example: It is desired to correct the oscillator at 125 KC. First set the heterodyne oscillator dial at exactly 125 KC. Switch on the crystal oscillator. The eighth harmonic of the heterodyne oscillator will beat with the 1000 KC crystal frequency. Rotate the corrector knob until the two signals are exactly at zero beat.

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Always turn the crystal off before attempting any frequency measurements.

MALFUNCTIONING OF FREQUENCY INDICATORS

Occasionally, it may be impossible to set the heterodyne oscillator to zero beat by adjusting the "corrector" condenser. This may be due to equipment failure, an error in dial setting or extremes of humidity.

No effort should be made to use the frequency indicator when the heterodyne oscillator frequency cannot be accurately checked.

Lacking a frequency indicator, the transmitter may be set by tuning a station on the desired frequency with the receiver. The transmitter is then set to zero beat with this frequency, using the receiver. This procedure should be followed only when the frequency indicator cannot be used.

EXAMPLE PROBLEMS

1. Why is it not advisable to make habitual use of the receiver instead of the frequency indicator when setting transmitter frequency?

   ANS: The station you hear may not be on the exact frequency desired. It is often difficult to exactly duplicate the frequency using the receiver. The frequency indicator is designed for the specific purpose of indicating frequency accurately.

2. When tuning the oscillator to compare its frequency with that of the crystal, numerous weak beat notes are heard in addition to the strong ones used as check points. Might this cause errors in setting heterodyne oscillator frequency?

   ANS: Yes. The weak beat notes are caused by high harmonics of the two oscillators beating together. The harmonics used as check points give much stronger beat notes because low order harmonics are used. Higher harmonics of an oscillator become quite weak. A little care in listening will prevent confusion and errors. Be especially careful not to allow too strong a signal to enter the frequency indicator.

CLASSROOM PROBLEMS

1. The "high" heterodyne oscillator band covers 2,000 to 4,000 KC. It is desired to check the calibration at 2,000, 3,000 and 4,000 KC. Which harmonics of the 1,000 KC crystal oscillator will beat with the fundamental frequency of the heterodyne oscillator?

   ANS:_____

2. The heterodyne oscillator is to be checked at 3,500 KC. Which harmonics of the heterodyne oscillator will beat with the 7th harmonic of the 1,000 KC crystal oscillator?

   ANS:_____

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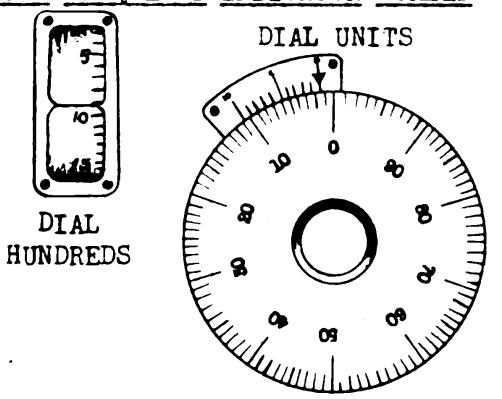
3. After setting the "corrector", the crystal oscillator must always be turned off before attempting to use the indicator on an outside signal. Why?

ANS:_____

READING FREQUENCY INDICATOR SCALES



The dial marked "dial units" is rotated by turning the knob. It is divided into 100 divisions. The vernier permits reading it to an accuracy of one-tenth division.

The "hundreds" dial is geared to the "units" dial so it moves up one division for each complete rotation of the "units" dial. It is divided into 50 divisions.

Thus there are 5,000 divisions covering the range of the tuning condenser. Each division is readable to one-tenth division by use of the vernier.

To read: Read "hundreds" scale first 09
Read "units" scale second 01
Read vernier last .4

Put together 0901.4 (Do NOT add)

Always read the "hundreds" and "units" scale to <u>two</u> numbers (as 02, 09, 22, etc.).

"Hundreds" scale	"Units" scale	Vernier	Correct answer	Common wrong answer
10	01	1	1001.1	101.1
	Always read "hundreds" and "units" <u>to two numbers</u>.			
09 (almost)*	98	3	0898.3	0998.3
	*The "09" is almost up to its line. The answer is near to 09 but is actually 0898.3			
10	1	4	1001.4	101.4
	The reading of the "units" scale omitted the necessary "0"; it should be read "01".			

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EXAMPLE PROBLEMS

1. The "hundreds" scale is just about on 22. The "units" is at 93. The vernier is at 9. What is the complete reading?

   ANS: 2193.9

2. The "hundreds" scale is just about on 18. The "units" is at 3. The vernier is at 0. What is the proper reading?

   ANS: 1803.0

CLASSROOM PROBLEMS

1. The "hundreds" scale is just about on 25. The "units" scale is at 0. The vernier is at 9. What is the correct reading?

   ANS:_____

2. The "hundreds" scale is half way between 7 and 8. The "units" scale is at 56. The vernier is at 9. What is the reading?

   ANS:_____

3. The "hundreds" scale is between 40 and 50. The "units" scale is at 30. The vernier is at 0. What is the reading?

   ANS:_____

CALIBRATION CHARTS

Dial	Kilocycles
1000.0	9000.0
1088.0	9100.0
1180.5	9200.0
1270.4	9300.0
1370.4	9400.0
etc.	

Charts like the one above are used with most frequency indicators. These charts make it unnecessary to calibrate the dials directly in kilocycles.

Such a chart will give kilocycles from dial reading or vice versa.

Known	Process	Answer
1000.0 dial	Direct from chart	9000 kc.
9050 kc.	Half way between 1000.0 and 1088.0	1044.0 dial
9090 kc.	There are 88 dial divisions for each 100 kc. or .88 divisions for each 1 kc. Then, 90 x .88 = 79.2	1079.2 dial

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Known	Process	Answer
1020 dial	There are 100 kc. for each 88 dial divisions or 100/88 = 1.13 kc. per division. Then 1.13 x 20 = 22.6	9022.6 kc.

EXAMPLE PROBLEMS

1. What frequency is dial division 1275.4?

   ANS: 100 divisions are 100 kc. So 1 division is 1 kc.

   1275.4
   1270.4
   5.0 divisions higher than 9300 kc.

   5 divisions is 5 kc. so 9300 + 5 = 9305 kc.

2. What dial setting is 9399 kc.?

   ANS: In this part of the chart 1 kc. = 1 dial division

   To increase 99 kc. requires 99 more dial divisions, so:

   1270.4 + 99 = 1369.4 dial reading.

CLASSROOM PROBLEMS

1. What frequency is a dial setting of 1100.0?

   ANS:_____

2. What frequency is a dial setting of 1201.5?

   ANS:_____

3. What dial setting is 9222.2 kc.?

   ANS:_____

4. What dial setting is 91111.1 kc.?

   ANS:_____

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HOMEWORK

1. Why must a preliminary "warm-up" period be allowed before attempting to use a frequency indicator?

   ANS:_____

2. Why is it important to adjust the heterodyne oscillator corrector before making frequency measurements?

   ANS:_____

3. If unable to obtain zero beat by rotating the corrector knob, what would you check before deciding the indicator was not usable?

   ANS:_____

4. What error might result if the crystal oscillator in the frequency indicator is left "on" while using the indicator for frequency measurements?

   ANS:_____

5. On a frequency indicator scale, what are the following readings?

Hundreds	Units	Vernier	Answer
0	07	9	_____
14	4	4	_____
36	22	0	_____
49	99	9	_____

6. Fill in the missing number, using the calibration chart previously given:

Dial	Kilocycles
1111.1	_____
1300.0	_____
_____	9381.0
_____	9007.5
1277.3	_____

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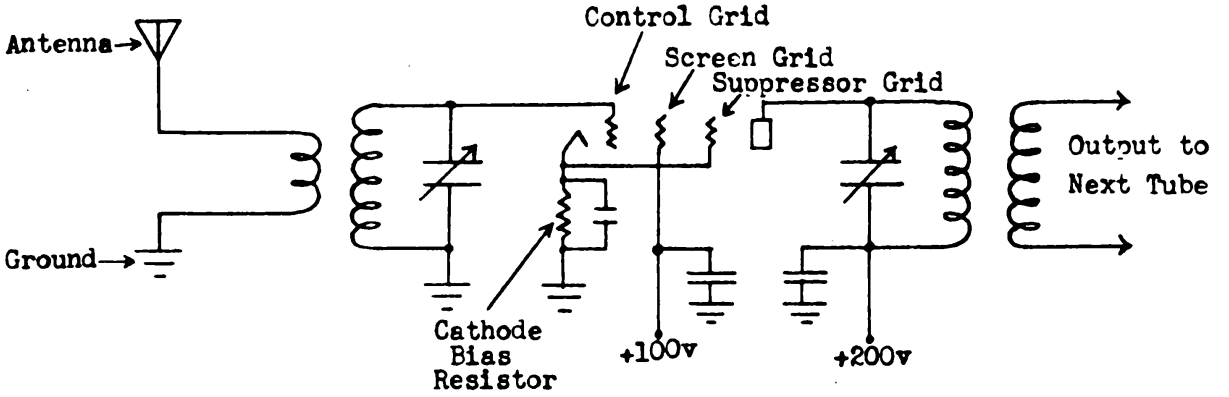
RADIO FREQUENCY AMPLIFIERS FOR RECEIVERS



Radio frequency amplifiers for receiving operate in the same manner as those used in transmitters.

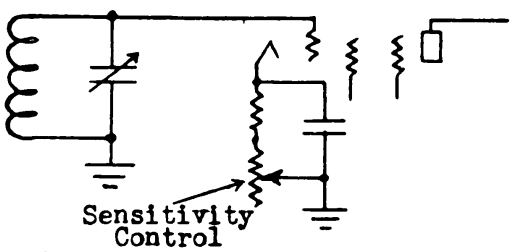
Pentode tubes are often used. These give large voltage amplification and do not require neutralization.

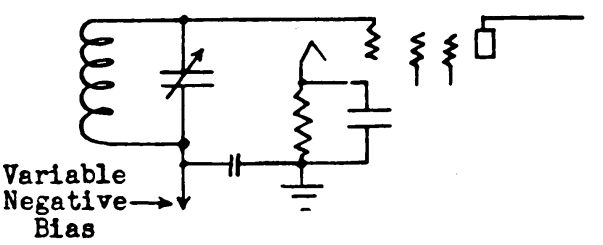
The grid driving voltage is obtained from the antenna. The antenna is inductively coupled to a tuned grid tank. This tank tends to reject all frequencies except the particular one desired.

The tube is operated with cathode bias as a Class A amplifier. Thus, the RF impulses arriving at the antenna are exactly repeated by variations in plate current.

RF amplifiers are used to aid in the rejection of unwanted signals and to increase the strength of those on the desired frequency.

Received signals vary in strength over wide limits. It is desirable to provide the RF amplifier with a sensitivity control to limit strong signals. Otherwise, succeeding tubes will not faithfully reproduce the original signal. This is called "distortion". Distortion, due to very strong signals, is called "blocking". It causes poor quality or even an actual reduction in signal strength in the headphones.





As shown above at the left, a variable resistor may be connected in series with the cathode resistor. Increasing the amount of resistance places the cathode at a higher positive voltage. This gives the same effect as adding negative grid bias and will limit the amplification.

As shown above at the right, the sensitivity of the amplifier may also be limited by the use of more negative grid bias. A method of doing this automatically will be shown later.

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EXAMPLE PROBLEMS

1. Could the comparative strength of the desired signals be further increased by tuning the antenna circuit?

   ANS: Yes. This is done in some types of receivers. It requires an additional tuning control and the setting must be changed each time the frequency or antenna is changed.

2. The sensitivity control is sometimes called a "volume" control Is this correct?

   ANS: No. The sensitivity control does have an effect on the output volume of the receiver but its primary purpose is to adjust the receiver to the proper sensitivity for the strength of the signal being received.

CLASSROOM PROBLEM

1. The power in the signal received from a distant station is extremely small. Why does this make it advantageous to operate the RF amplifier tube in Class A?

   ANS:_____

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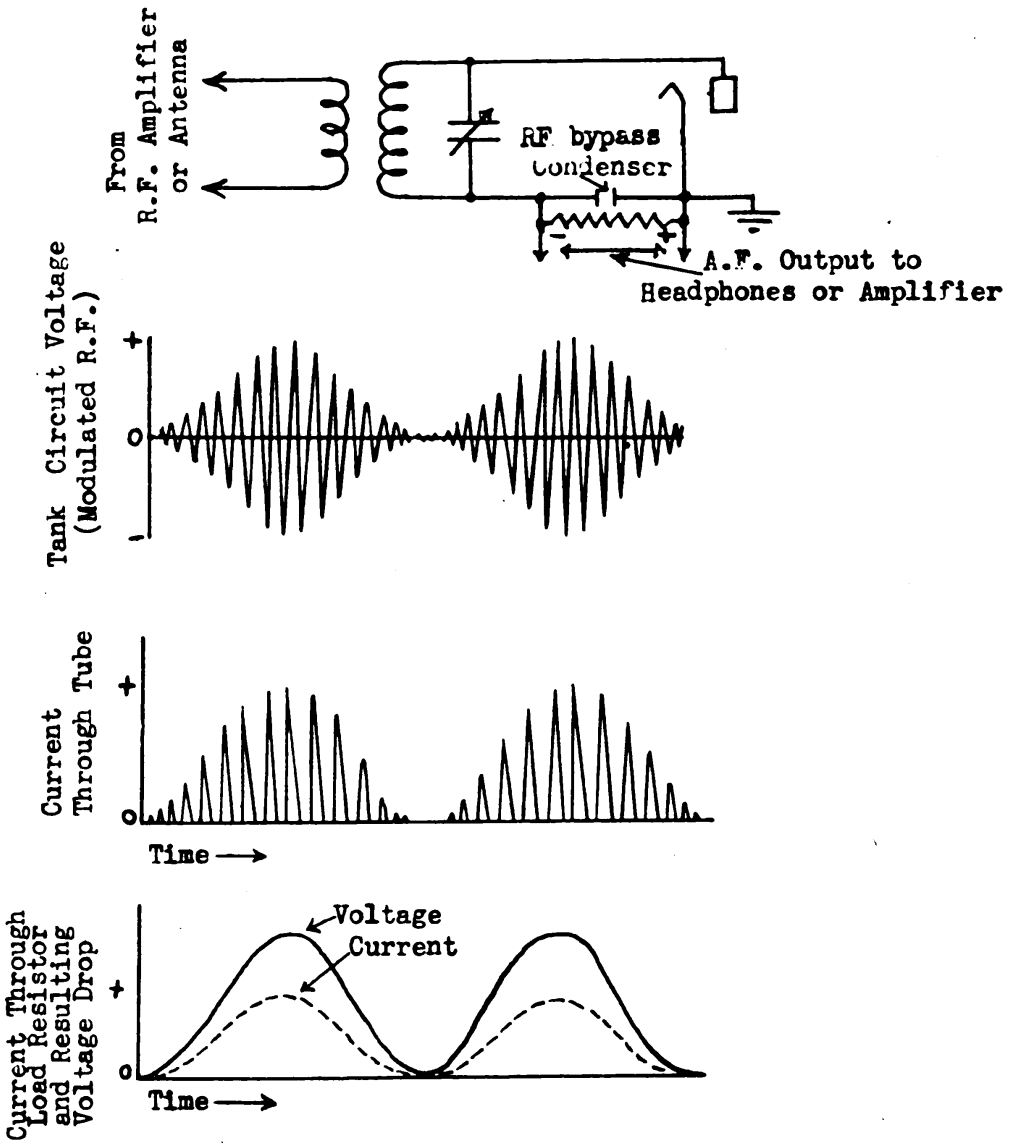
DETECTION
(Rectification of RF)



The diode permits current to flow between cathode and plate only during the positive half of the cycle of the incoming RF voltage. All modulated signals look like the top diagram. In the previous sections, only the upper half was shown for simplicity.

The current through the tube is pulsating DC.

The RF by-pass condenser is connected across the load resistor. The condenser charges as the voltage rises and discharges as the voltage falls. This effectively removes the RF pulsations of voltage and current. The condenser is chosen to have a small enough capacity so it will not affect the audio frequency pulsations and bias will follow the audio frequencies accurately.

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The load resistor has high resistance. There will be a large voltage drop across it due to the flow of current through it.

A pair of headphones connected across the load resistor will produce sound of the same pitch as was used originally to modulate the transmitter.

The above process is called "detection". The diode is the "detector" tube.

EXAMPLE PROBLEMS

1. What is the effect if the RF by-pass condenser has too large a capacity?

   ANS: It will tend to smooth out the audio frequency pulsations as well as the RF. The response of the detector circuit will be greatly reduced, especially for the higher audio frequencies.

2. Many receivers use three, four or five element tubes for detection. Do these operate differently from the diode?

   ANS: The principle of operation is about the same. The additional elements are used, in conjunction with a DC plate supply, to amplify the rectified signals.

3. In a receiver using a radio frequency amplifier ahead of the detector, could the tuning condensers be mechanically connected so only one tuning dial is required?

   ANS: Yes. This is commonly done in receivers.

CLASSROOM PROBLEMS

1. What is the effect on the audio frequency output of a detector if the resistance of the load resistor is reduced?

   ANS:_____

2. Will there be audio frequency output from a detector of this type if the original RF signal is not modulated? Explain.

   ANS:_____

   _____

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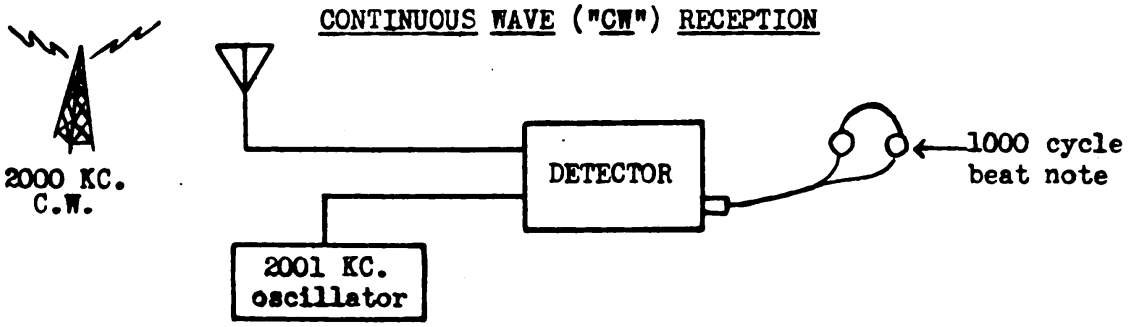
CONTINUOUS WAVE ("CW") RECEPTION



The majority of radiotelegraph transmission is by means of continuous wave (unmodulated) RF. This is commonly known as "CW".

A CW signal completely free of audio frequency modulation would be unreadable because the output of the detector would be a steady DC voltage with no audio frequency.

Receivers designed for CW reception have a built-in oscillator which can be tuned to a frequency near that of the CW signal. The output of this oscillator is fed into the detector, producing an audible beat note. Any desired pitch can be produced in the headphones, depending on the relative frequencies of the "beat" oscillator and the signal being received by the detector.

EXAMPLE PROBLEM

1. Some receivers use a single tube to perform the functions of both detector and beat oscillator. Is the principle of operation the same as above?

   ANS: Yes.

CLASSROOM PROBLEMS

1. A detector tube is receiving a 465 KC CW signal. The beat oscillator is tuned to 465.5 KC. What is the frequency of the beat note?

   ANS:_____

2. A detector tube is receiving a 465 KC CW signal. The beat oscillator is tuned to 464.5 KC. What is the frequency of the beat note?

   ANS:_____

3. A detector tube is receiving a 465 KC CW signal. What happens to the pitch of the beat note as the beat oscillator is tuned through a range starting at 460 KC and ending at 470 KC? Would the result be the same if the beat oscillator remained on 465 KC and the signal was varied from 460 to 470 KC?

   ANS:_____

   _____

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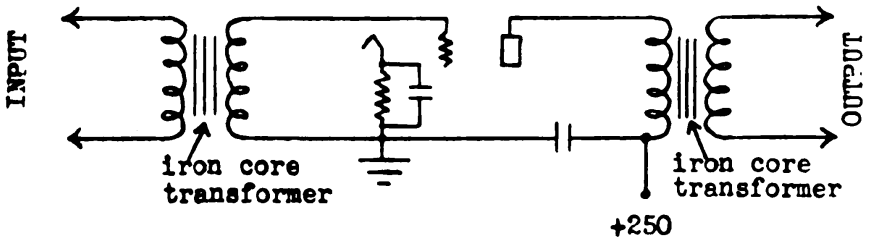
AUDIO FREQUENCY AMPLIFIERS



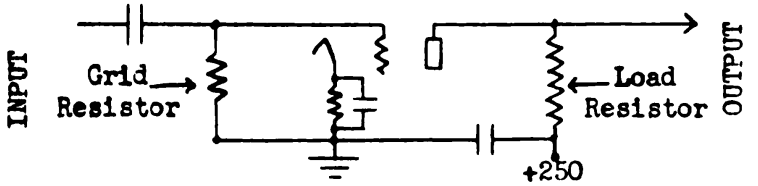
TRANSFORMER COUPLED AMPLIFIER

Audio frequency amplifiers are used to boost the low AF output of the detector tube to a value giving louder headphone signals or sufficient for a loud speaker.

A single tube amplifier is always operated in Class A to give faithful reproduction of the output of the detector. Cathode bias is often used to avoid having a separate bias battery.

The amplifier shown above operates in the same manner as the speech amplifier in a radiotelephone transmitter.

If the receiver is designed to have high AF output (for loud speaker operation), this amplifier may be followed by a push-pull amplifier operated in Class B.



RESISTANCE COUPLED AMPLIFIER

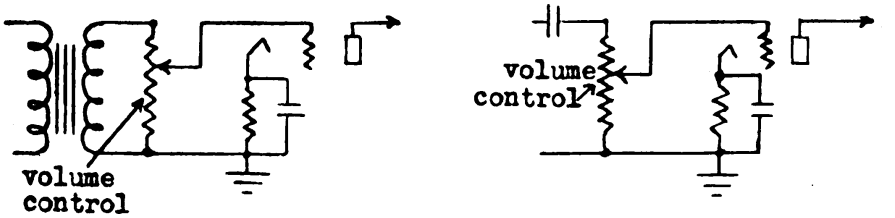
The resistance coupled amplifier is used where high quality reproduction is desired. It will give this because the resistors have constant resistance no matter what audio frequency is used.

The grid is coupled to the preceding tube through a condenser. The condenser is of a size which offers little reactance to the passage of audio frequency current. It blocks any interaction between the grid bias and the amplifier tube and the DC plate voltage of the preceding tube.

EXAMPLE PROBLEM

1. Where might a volume control be placed in audio frequency amplifier?

ANS:



The volume control is a resistor connected across the AF input to the grid. The grid is connected to an arm which is moved along the resistor to place an AF voltage on the grid which gives the desired volume of AF output. Another name for a resistor of this type is a "potentiometer".

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CLASSROOM PROBLEMS

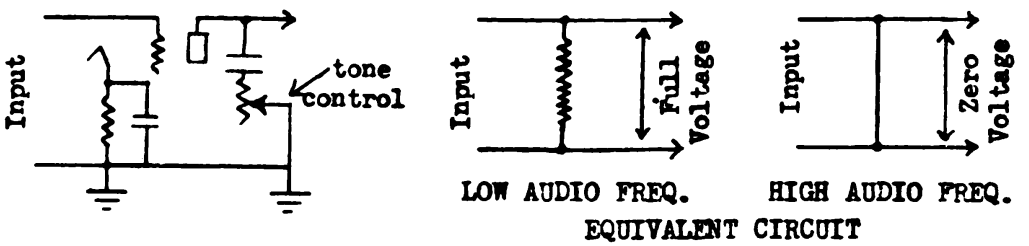
1. At what point on the potentiometer will the largest AF volume be obtained? The maximum AF volume?

   ANS:_____

2. Why are there no tuned circuits in an audio frequency amplifier?

   ANS:_____

TONE CONTROLS



It is often desirable to reduce the volume of the higher audio frequencies. This can be helpful in reducing the effect of static and other undesired noise.

The condenser has a low reactance at high audio frequencies. The circuit is actually a filter circuit having an adjustable element.

EXAMPLE PROBLEM

1. What position of the tone control gives the maximum reduction in high audio frequencies?

   ANS: The variable resistor set for zero resistance. The condenser is practically a short-circuit for high frequencies coming from the tube.

CLASSROOM PROBLEMS

1. Does the tone control increase the volume of the lower audio frequencies or does the receiver simply sound that way because the high frequencies are eliminated?

   ANS:_____

2. What position of the tone control gives least reduction in high audio frequencies?

   ANS:_____

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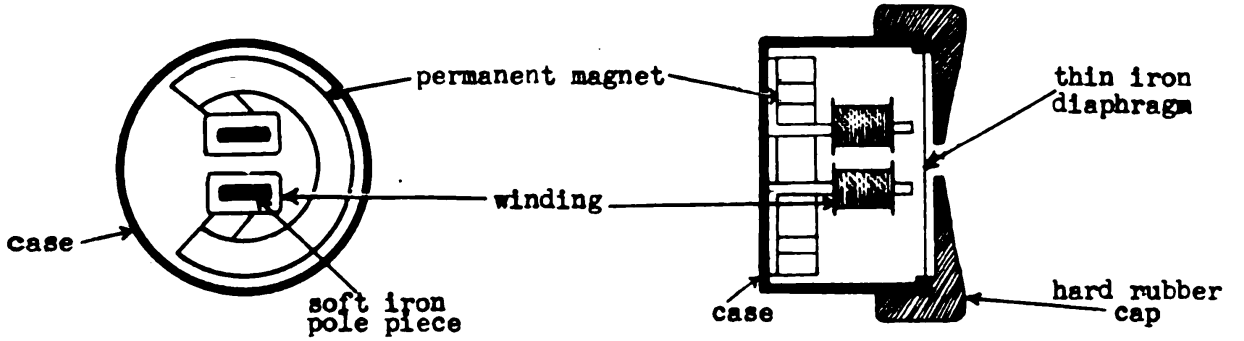
HEADPHONES
(AF to sound)



The permanent magnet exerts a steady pull on the iron diaphragm through the soft iron pole pieces. This keeps the diaphragm bent in slightly, but never enough to actually touch the pole pieces.

The windings on the pole pieces are connected in series. They consist of thousands of turns of small, insulated copper wire. When a varying current is passed through these windings, the magnetic field acting on the diaphragm is varied in accordance with the changes in current. This causes the diaphragm to vibrate in accordance with the changes in current.

The vibration of the diaphragm causes sound, which passes to the ear through the hole in the center of the headphone cap.

The usual headset for radio use consists of two headphones, connected in series by the headphone cord and attached to an adjustable headband.

EXAMPLE PROBLEMS

1. The headphones commonly used on aircraft are known as "anti-static" type. Does this mean that they eliminate static?

   ANS: The movement of the diaphragm is limited mechanically to protect the ear from extremely loud sounds, such as might be caused by a burst of static. It does lessen the effect of static on the ear.

2. Will headphones respond to radio frequency currents?

   ANS: No. The diaphragm will not follow frequencies above the audible range.

CLASSROOM PROBLEMS

1. Explain why no sound will be produced if a steady direct current is flowing through the headphone windings.

   ANS: _____

2. Why are so many turns of wire used on headphone windings?

   ANS: _____

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HOMEWORK

1. Why is it unnecessary to neutralize an RF amplifier using a pentode?

   ANS:_____

2. Why is it desirable to use low sensitivity when very strong signals are received?

   ANS:_____

3. An extremely strong RF signal is supplied to a diode detector. What may happen to the AF voltage peaks? Why?

   ANS:_____

4. Many CW signals carry a slight percentage of tone modulation. Why does a beat oscillator aid the operator in reading such signals?

   ANS:_____

5. An iron core inductor is sometimes substituted for the load resistor in a resistance coupled amplifier. Such an amplifier is an "impedance coupled" amplifier. What is the advantage of using the inductor? What is the disadvantage?

   ANS:_____

   _____

6. A condenser is sometimes connected in series with headphones in simple receivers so that there will be no DC voltage between the headphone windings and ground. Why is this an advantage?

   ANS:_____

7. What means, other than a condenser, might be used to isolate headphones from DC voltage? (This is the usual method employed today.)

   ANS:_____

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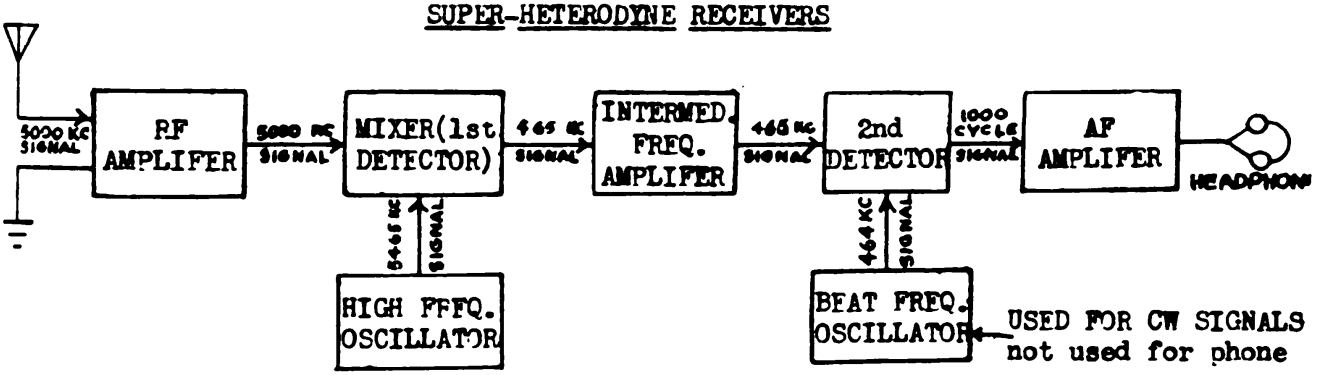
SUPER-HETERODYNE RECEIVERS



The incoming signal is first amplified by the RF amplifier. The output of the RF amplifier is fed into the grid of a second tube called a "mixer" tube.

The output of a high frequency oscillator is fed into another grid of the mixer tube. These two signals beat together to produce a beat note of much lower frequency. By adjusting the frequency of the high frequency oscillator in accordance with that of the received signal, this beat note can always be maintained at 465 KC, no matter what the frequency of the received signal. The mixer tube is often called the first detector or converter.

The 465 KC signal is called the "intermediate frequency" signal. It is amplified by the intermediate frequency amplifier, which is tuned to 465 KC.

The output of the intermediate frequency ("IF") amplifier is fed to a detector tube ("second detector") where it is changed to an audible signal. If a CW signal is being received, a beat frequency oscillator is required to make it readable.

The audio frequency amplifier increases the volume of the AF signal to the level desired for headphones or loud speaker.

This is a "super-heterodyne" receiver. Such receivers are used almost exclusively for high frequency reception.

The super-heterodyne receiver takes advantage of the fact that low frequency RF amplifiers can be built to have greater selectivity and larger amplification than those operating on higher frequencies.

In some super-heterodynes, a single multi-element tube is used as both mixer and high frequency oscillator tube. The principle of operation is the same as when two separate tubes are used.

EXAMPLE PROBLEMS

1. The above example shows an intermediate frequency of 465 KC. Is this frequency used in all super-heterodyne receivers?

   ANS: Most super-heterodynes use an intermediate frequency of 450 to 950 KC. However, those designed for very high frequency reception may use an IF much higher than this.

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2. The high frequency oscillator is set on 4500 KC. The RF amplifier and mixer grid circuits are both tuned to 5000 KC. The IF is 500 KC in this case. What will happen if the antenna picks up a strong signal on 4000 KC?

   AND: A sufficiently loud signal on 4000 KC may get past the tuned circuits. In that case, it will cause a 500 KC intermediate frequency signal as does the desired signal. Such signals are called "images". Generally, they will not be strong enough after getting through the tuned circuits to cause undue difficulty.

3. The RF amplifier, mixer, and high frequency oscillator each require a variable condenser for tuning. How are all three tuned by rotating a single dial?

   ANS: The inductors and circuits are so designed that the three tuning condensers can be placed on one shaft and tuned simultaneously as all circuits cover the tuning range. Some receivers use two RF amplifiers, one after the other (two "stages" of RF amplification). Such receivers require four tuning condensers to be turned simultaneously.

CLASSROOM PROBLEMS

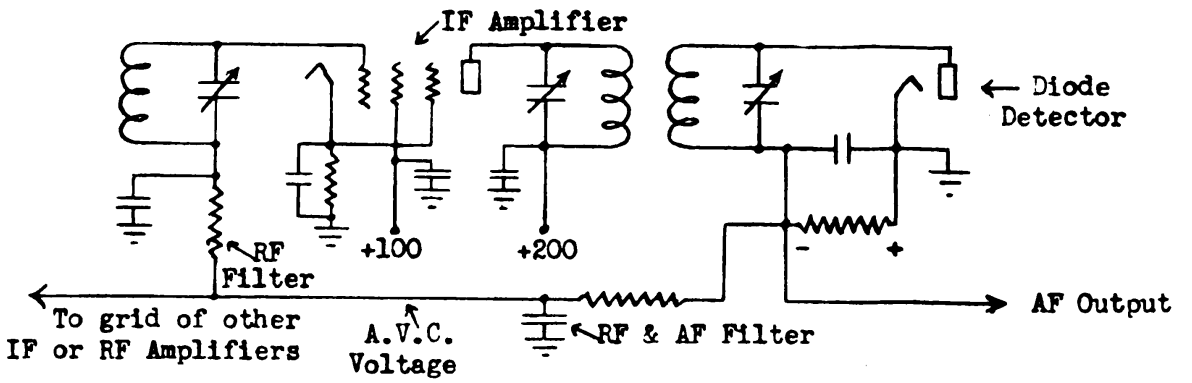
1. A receiver with 900 KC intermediate frequency is tuned to 10,000 KC. What is the "image" frequency when the high frequency oscillator is set at 10,900 KC? What is the "image" frequency when the high frequency oscillator is at 9,100 KC?

   ANS:_____

2. The tuning condensers in a receiver can cover only a limited frequency range (or "band"). Otherwise, signals would be crowded very close together on the dial. One way of increasing the number of frequency bands covered is to provide several inductors ("coils"), any set of which may be switched in to give the correct inductance for the desired band. If a coil is open on one band, does this mean all bands are inoperative?

   ANS:_____

AUTOMATIC VOLUME CONTROL



The amount of DC voltage across the load resistor of a diode varies directly with the strength of the RF signal it is rectifying.

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This voltage can be used to provide automatic control of the receiver sensitivity. As the signal becomes stronger, the voltage across the load resistor becomes higher. This automatically places more negative bias on the grids of the RF and IF amplifier tubes, thereby reducing their sensitivity. Thus, the sensitivity will be high for weak signals and low when strong signals are received. This is an automatic volume control (AVC).

The RF filters shown are resistor-condenser filters. These prevent RF voltage from passing through the AVC circuit where it might upset the operation of the receiver.

Most broadcast receivers use AVC at all times to prevent undue changes in volume as the receiver is tuned to various stations.

High frequency communications receivers are usually equipped with AVC. Such receivers have switches to disconnect the AVC voltage when it is desired to have sensitivity controlled only by the manual sensitivity control.

AVC is not used on radio range receivers. It tends to conceal the relative strength of received signals, which is undesirable when flying on radio ranges.

EXAMPLE PROBLEM

1. The AVC system shown above starts reducing receiver sensitivity immediately on any signal received. How can it be arranged to reduce sensitivity only when fairly strong signals are received?

   ANS: Most receivers use two diodes in the same tube. The detector diode operates the same as before. AVC voltage is obtained from the second diode It is given a small amount of bias to prevent AVC voltage from being built up until the signal is strong enough to overcome this small bias.

CLASSROOM PROBLEM

1. One receiver applies AVC voltage to the grid of only one tube. Another type applies AVC voltage to the grids of three tubes. Which produces the more pronounced AVC action?

   ANS:_____

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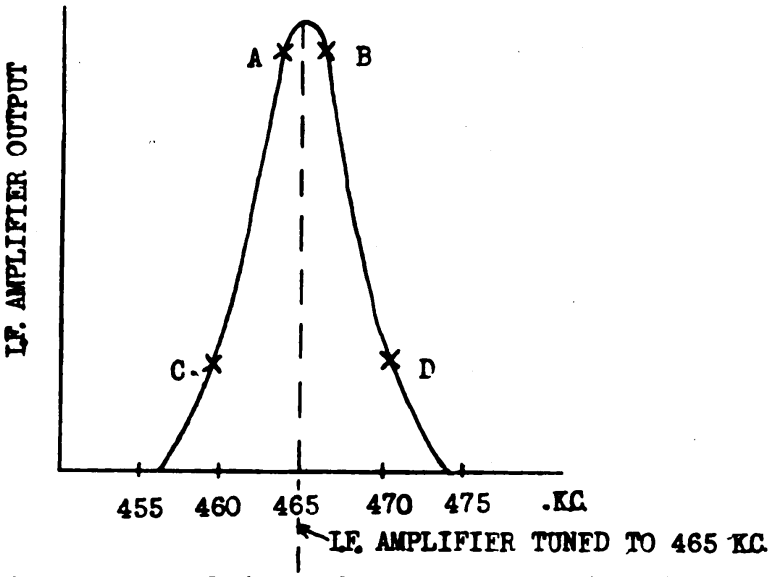
ADJUSTMENT OF BEAT FREQUENCY OSCILLATOR



The intermediate frequency amplifier of a super-heterodyne tunes quite sharply. It gives little output from signals more than a few kilocycles away from the frequency to which it is tuned.

Maximum amplification of the above IF amplifier is realized only when the high frequency oscillator is tuned so as to produce an intermediate frequency signal very close to 465 KC.

Super-heterodyne receivers have a panel adjustment which will vary the frequency of the beat frequency oscillator (BFO) over a range of several kilocycles. An incorrect BFO setting will considerably reduce the usefulness of such a receiver.

When the BFO is set at 464 or 466 KC (point A or B on the above curve), the maximum amplification of the IF amplifier is being used.

On the other hand, when the BFO is set at 460 KC (point C on the above curve), it is necessary to detune the high frequency oscillator to produce an IF of 459 or 462 KC in order to obtain the desired 1000 cycle beat note. Consequently, signal strength is greatly reduced because this is far to one side of the frequency at which the IF amplifier amplifies best.

The same is true when the BFO is set at 470 KC (point D on the above curve). It then becomes necessary to retune the high frequency oscillator to produce an IF signal of 469 or 471 KC. Again, signal strength will be greatly reduced.

EXAMPLE PROBLEMS

1. Describe the method of properly setting the beat frequency oscillator.

   ANS: With the BFO turned off, tune in a signal. Set the tuning dial at the point giving the strongest signal. Turn on the BFO and rotate its adjustment knob until a beat note of the desired pitch is obtained. The BFO adjustment should usually be left alone thereafter.

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2. Can the BFO be properly set even through no signal is heard?

ANS: Yes. The BFO causes an audible hiss in the receiver output. This changes in pitch as the BFO adjustment knob is rotated. The knob should be left near the point at which the pitch is lowest.

CLASSROOM PROBLEMS

1. The high frequency oscillator of a super-heterodyne receiver is controlled by the tuning dial. As you tune through a given station, are you changing the frequency of the signal fed to the IF amplifier?

ANS:_____

2. The BFO frequency is set part way down the curve shown on the preceding page. As the receiver is tuned through a station, the signal is noticeably stronger on one side of zero beat than the other. Explain why.

ANS:_____

_____

3. Describe the method that you would use to adjust a receiver <u>exactly</u> to a certain frequency by use of the frequency indicator. Assume that the reason for this was that you wished to hear a CW station the <u>moment</u> it comes on the air.

ANS:_____

_____

_____

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HOMEWORK

1. Interference with reception caused by "image" signals is called "image" interference. Would you expect image interference to be worse on a superheterodyne with no RF amplification or on one with a stage of tuned RF amplification?

   ANS:_____

2. Would you expect image interference on a simple receiver composed of a stage of RF amplification, detector and audio amplifier ("tuned radio frequency" receiver)?

   ANS:_____

3. Why would you expect less interference from stations on near-by frequencies when using a superheterodyne than with the receiver described in Question 2?

   ANS:_____

4. What is the advantage of a superheterodyne for high frequency reception?

   ANS:_____

5. Receivers designed to operate on one frequency often have a crystal to control the frequency of the high frequency oscillator. Is this crystal ground to the frequency to be received? If not, to what frequency is it ground?

   ANS:_____

6. A receiver equipped with AVC maintains AF output at near the same level over a large range of signal inputs. Still, the operator listening to the AF output can tell whether the signal being received is strong or weak. How?

   ANS:_____

7. Why should an operator be careful not to set the frequency of a BFO too far from the intermediate frequency of the receiver?

   ANS:_____

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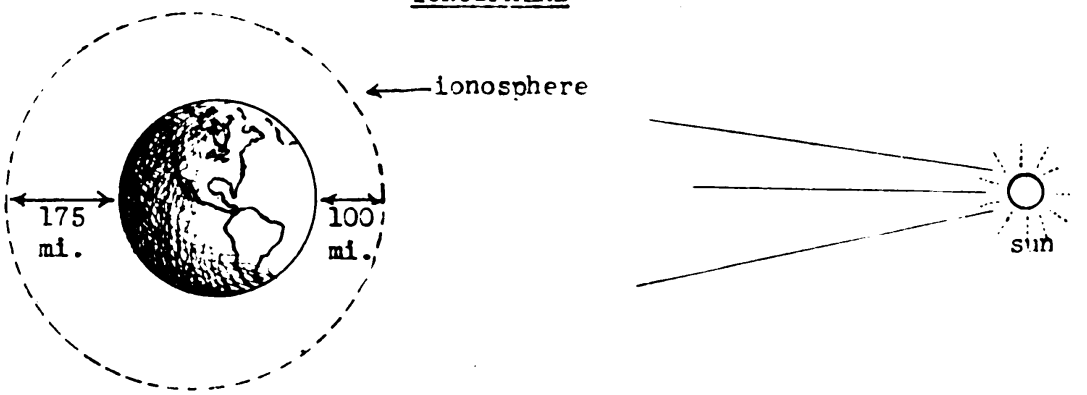
IONOSPHERE

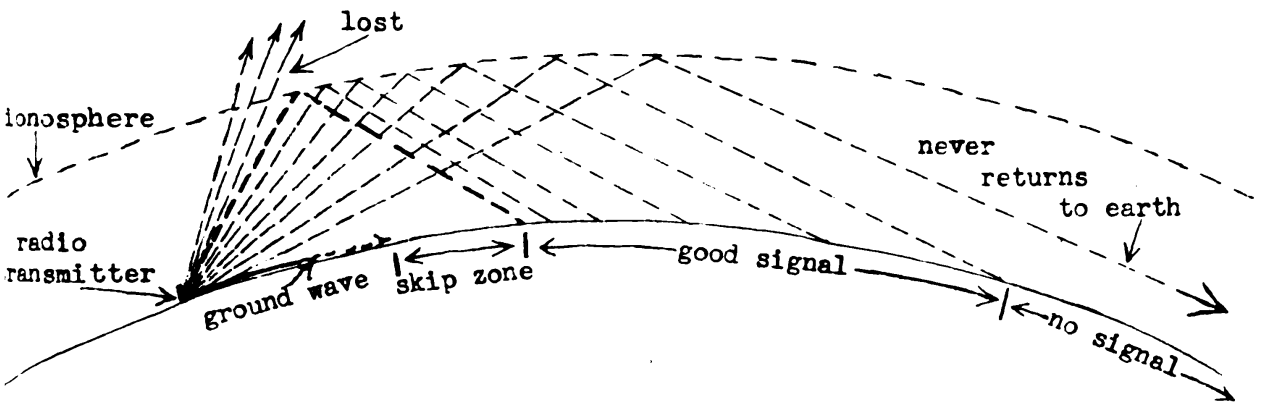


At 50 miles and more above the Earth's surface, the atmosphere becomes very thin. Radiation from the sun is extremely strong at such levels. It causes the thin gases to become electrically charged. The layer of electrically charged ("ionized") gas surrounding the earth is the ionosphere.

Actually, the ionosphere is composed of several layers of ionized gas. For purposes of explanation, only one layer need be considered.

This layer lies from 100 to 175 miles above the surface. The gas is very thin there. Ionization exists at all times.

The level of the ionosphere rises during the night and becomes lower during the day, when the sun's rays are striking it directly. It is lower during the summer than the winter, since the sun's rays strike it more directly in summer.



High frequency transmission (above 2 MC) takes two forms; the ground wave and the sky wave.

The ground wave travels close to the surface of the earth. Low frequency (200-400 KC) ground waves may travel for considerable distances. High frequency ground waves (above 2 MC) disappear sooner because they are absorbed by the earth more rapidly.

The sky wave must travel at upward angles from the antenna. This causes it to strike the ionosphere. The radiation leaving the antenna at high angles passes straight through the ionosphere and is gradually absorbed or lost in outer space. Radiation at very low angles is also reflected, but so far out that it never strikes the earth.

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EXAMPLE PROBLEMS

1. It is summer in the southern hemisphere when it is winter in the northern hemisphere. Does this cause the height of the ionosphere to be different in the two hemispheres?

   ANS: Yes. When it is winter in the northern hemisphere, the southern hemisphere is experiencing summer radio conditions.

2. The area between the point where the ground wave dies out and the point where the sky wave is first returned to earth is called the "skip" zone. Does this mean that no signal will be received from the transmitter in this zone?

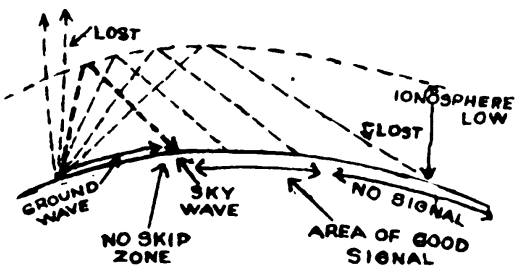
   ANS: Yes. When the skip zone covers a wide area, probably no signal at all will be received from the station when flying in this area. When the skip zone covers only a narrow area, it may be possible to hear parts of the transmission.

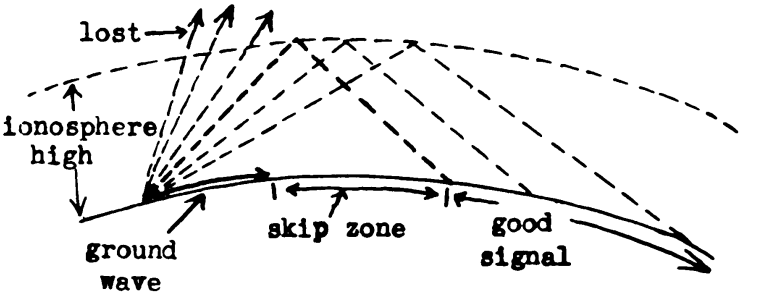
CLASSROOM PROBLEM

1. Antennas may be constructed which will concentrate the radiation at one definite upward angle. Why are such antennas undesirable for a transmitter whose signals need to be audible over a wide area?

   ANS:_____

COMPARISON OF DAY AND NIGHT TRANSMISSION





DAY NIGHT

During the day, the ionosphere is low. The sky wave may be reflected back to earth comparatively close to the transmitter.

At night, the ionosphere becomes higher. The first point at which the sky wave is returned to the earth is considerably farther from the transmitter. The furthest wave reflected to the earth is at a much greater distance from the station at night.

Radio waves are absorbed by ionization along their path. Thus, signals become gradually weaker with distance. In daytime this effect is greater than at night.

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EXAMPLE PROBLEM

1. **Are the maximum upward angles at which reflection occurs constant?**

   ANS: No. The density of the layer is greater in daylight. Higher angles of radiation are reflected during the day.

CLASSROOM PROBLEMS

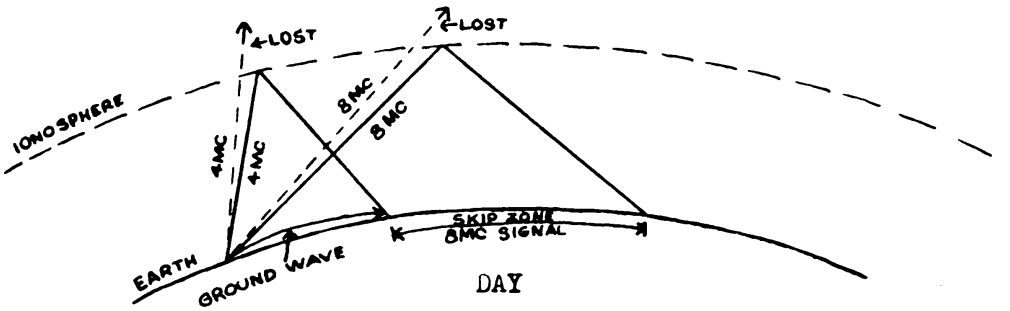
1. The ground wave is generally good for transmission on high frequencies up to about 50 miles. If the sky wave is first reflected to earth at a distance of 200 miles from the transmitter, what distance does the skip zone cover?

   ANS:_____

2. If it is desired that there be no skip zone, at what distance from the transmitter must the sky wave first be reflected to earth?

   ANS:_____

EFFECT OF FREQUENCY ON REFLECTION

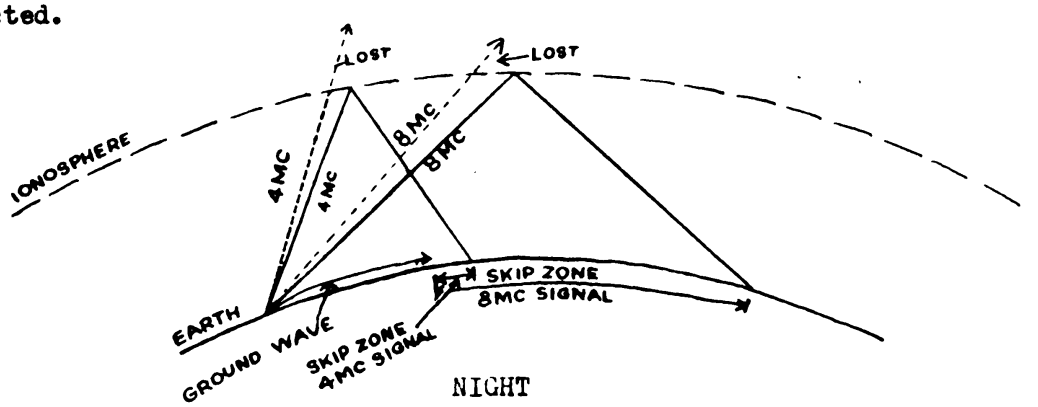


DAY

Frequency has a direct effect on the angles of radiation which will be reflected.

At frequencies near 3 MC, the angle can be quite high before radiation passes on through the ionosphere and is lost.

At higher frequencies, high angle radiation is lost. Only lower angle radiation is reflected.



NIGHT

Some of the higher angles reflected during the day are lost at night. In addition

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the reflecting layer is higher at night. The skip zone, if any, is greater at night for a given frequency.

EXAMPLE PROBLEM

1. Domestic airlines desire to maintain communication without skip effects. What change in frequency is usually made during the night?

   ANS: A lower frequency (near 3 MC) can be used at night to avoid having a skip zone.

CLASSROOM PROBLEMS

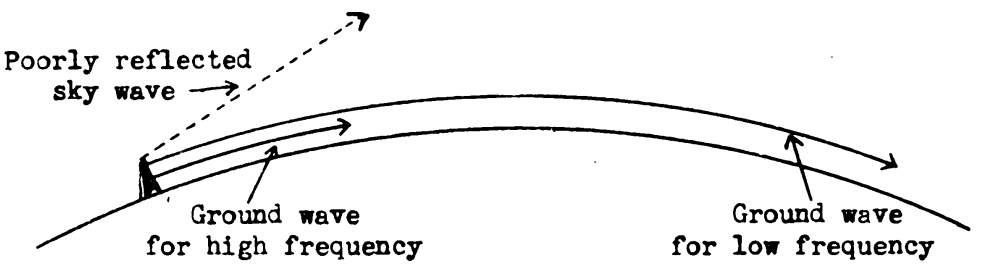
1. During the summer months, domestic airlines are frequently able to maintain communication on their "day" frequencies all night with little skip effect. Why?

   ANS:_____

2. During the winter months, domestic airlines usually change to a lower "night" frequency at night to avoid skip effect. Why is this necessary in winter?

   ANS:_____

LOW FREQUENCY TRANSMISSION



Ground waves from high frequency transmitters are rapidly absorbed by the ground. They are good for satisfactory communication up to 40 or 50 miles.

Ground waves from low frequency transmitters are not absorbed as rapidly. At frequencies of about 400 KC, they are satisfactory for communication up to about 75 miles during the day and 200 miles at night.

Over water, low frequency ground waves are absorbed even more slowly. Low frequency communication is more satisfactory over water than over land and extends to greater distances.

The maximum distance covered by low frequency ground waves depends largely on the amount of transmitter power used. Large transmitters of 10 to 100 KW may cover several thousand miles regularly, day or night.

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EXAMPLE PROBLEM

1. Variations in the height and makeup of the ionosphere frequently cause difficulties in maintaining high frequency communications. Do these affect low frequency communications?

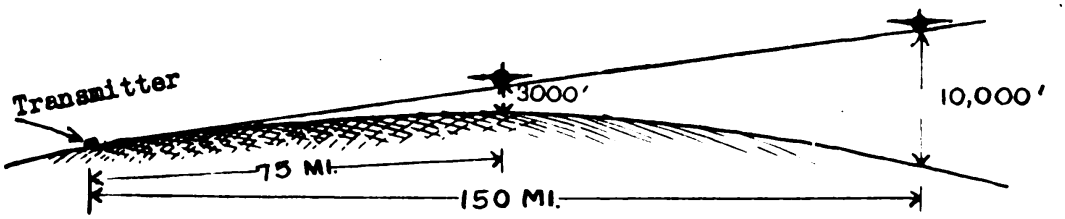
   ANS. No. Because low frequency communication depends principally on the ground wave - not much on reflection of the sky wave.

CLASSROOM PROBLEM

1. Efficient transmission on low frequencies requires longer antennas than can be carried on aircraft. In addition, aircraft transmitters are limited to rather low power. Why does this make high frequencies for aircraft usually preferable to low frequencies?

   ANS:_____

ULTRA HIGH FREQUENCY TRANSMISSION



The ultra high frequencies are those above 50 MC.

Ground waves from ultra high frequency ("UHF") transmitters are absorbed by the ground so rapidly that ground wave transmission is good for only a few miles.

Sky waves from ultra high frequency transmitters are not reflected back to earth. All except very low angle radiation passes on through the ionosphere. Radiation which might be reflected is at such a low angle that the reflection does not touch the earth.

Communication on ultra high frequencies is limited practically to line of sight. A little bending of the radiation occurs in the atmosphere, usually making communication a few miles beyond line of sight possible. Increased power adds little to the distance which can be covered.

Ultra high frequency is well adapted to aircraft communication at distances up to 50 to 150 miles, depending upon the height of the aircraft and intervening terrain. Static is often prevalent on high and low frequencies, but is hardly noticeable on ultra high frequencies.

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EXAMPLE PROBLEM

1. Do variations in the height and makeup of the ionosphere have any effect on ultra high frequency communication?

   ANS: No. UHF communication does not depend on the ionosphere. It goes right through it.

CLASSROOM PROBLEM

1. Why is UHF communication not practical when an aircraft is several hundred miles away from a ground station?

   ANS:_____

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HOMEWORK

1. You are located in the skip zone of a station 200 miles away. Does this mean you will not be able to receive a station 1,000 miles away?

   ANS:_____

2. If you are unable to contact a near-by station because of skip, how might you get a message to this station if you can contact another station some distance away?

   ANS:_____

3. If you are unable to contact a near-by station because of skip, what change in frequency would you make?

   ANS:_____

4. If flying in the southern hemisphere during January, would you expect summer or winter radio conditions? At the equator?

   ANS:_____

5. Why are high frequencies generally preferable to low frequencies for aircraft communication?

   ANS:_____

6. Why is the altitude of the plane an important factor in determining the distance which can be covered by UHF communication?

   ANS:_____

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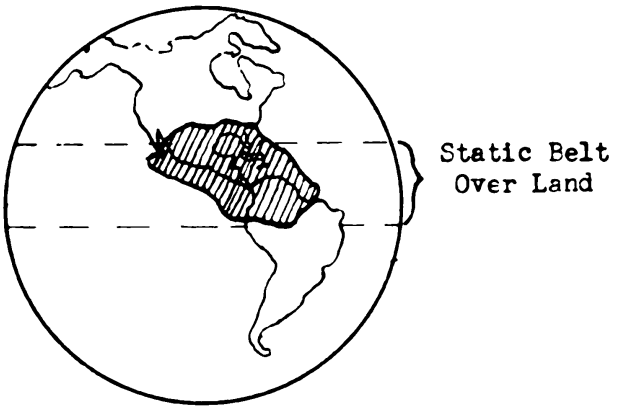
STATIC



Static heard in radio receivers is the result of electrical disturbances in the atmosphere.

Local thunderstorms may produce static audible within a few miles of such storms.

Most of the static ordinarily heard has its source in the tropics. Static is not concentrated on one frequency; it is spread over a very wide range of frequencies, diminishing as frequency increases. It arrives at the radio receiver by the same path as the radio signals.

Static on high frequencies may actually be louder at a distance from the tropics than it is nearby, because of skip effect.

Static originates mainly on land. Consequently, it may be very loud at a land station near its source and not loud to a ship well out at sea.

Static interference is most pronounced at frequencies below 5 or 6 MC. Its effect decreases at higher frequencies. It is seldom bothersome above 15 MC.

EXAMPLE PROBLEM

1. Can static be tuned out of a receiver in the same way as an undesired signal?

   ANS: No. Static covers too wide a range of frequencies.

CLASSROOM PROBLEMS

1. A plane over the sea in the tropics may be able to hear a shore station with little interference from static. Does this necessarily mean that the shore station is also experiencing little static disturbance?

   ANS:_____

2. In problem number 1, the airplane has a 50 watt transmitter. The ground station has a 10 KW transmitter. For uniform reception of signals, which should have the higher power?

   ANS:_____

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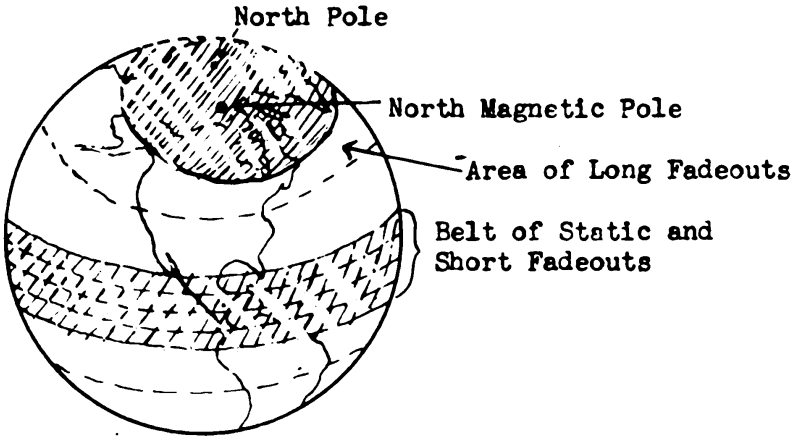
FADEOUTS



A radio fadeout is the absence of all signals on the medium and high frequencies. Low frequencies (400 KC and below) and ultra high frequencies (above 50 MC) are not affected.

Radio fadeouts occur in areas near the poles and in tropical areas.

Those near the poles are caused by intense ionization resulting from magnetic storms. Aurora borealis effects are heightened during such storms. The ionosphere layers become disarranged and broken up. The result is the total absence of radio signals which ordinarily arrive by reflection from the ionosphere. Such a fadeout may last for several days. The effect of a magnetic storm may be noticeable as far south from the poles as the central United States.

Fadeouts in the tropics are caused by intense ionization for some distance below the ionosphere. The layers of the ionosphere are still intact, but signals are absorbed by the ionized atmosphere below them. Such fadeouts generally last only a few hours. They develop very rapidly and end rapidly.

EXAMPLE PROBLEM

1. Why are low frequency ground waves and ultra high frequency line of sight transmissions not affected by fadeouts?

   ANS: They do not depend on the ionosphere and so are not affected by changes in it. Even very intense ionization does not extend to the earth's surface, so such waves continue to travel without hindrance.

CLASSROOM PROBLEM

1. Will a fadeout affect ground wave communication on high frequencies?

   ANS:_____

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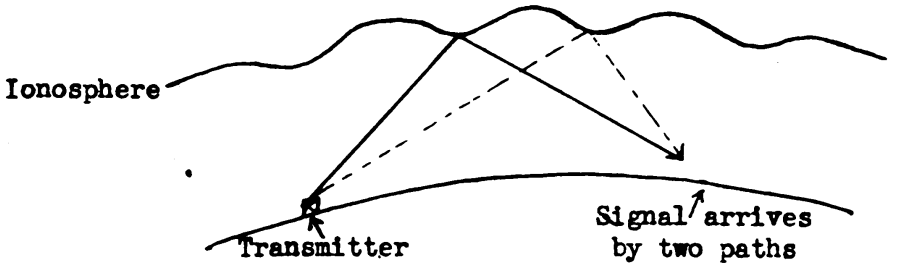
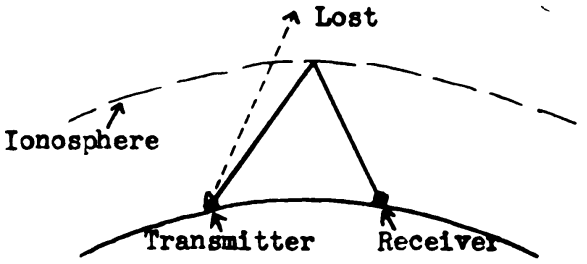
FADING

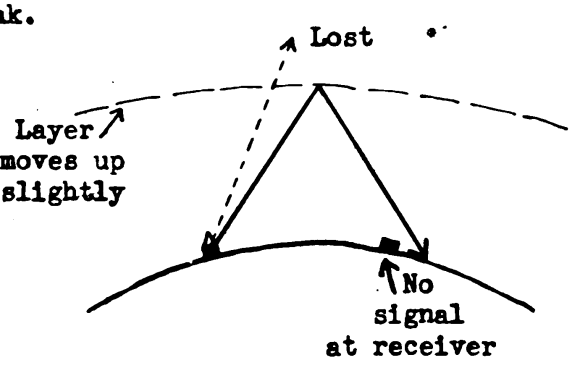


The signal may arrive at the receiver by two or more paths.

Since the paths are not the same length, the two or more signals received will not necessarily be in phase. When they are in phase, a strong signal will result in the receiver. When they are out of phase, the receiver signal will be very weak.

Variations in the ionosphere will cause changes in signal path. Thus, the receiver signal may be alternately strong, then weak.





Fading may also result when the receiving station is located close to the edge of the skip zone. Very small variations in the height of the ionosphere will cause the signal to fade in and out. This may occur at a rapid rate.

EXAMPLE PROBLEM

1. Does fading occur on low frequencies?

   ANS: Yes. Fading is noticeable at night on low frequencies. The sky wave is often reflected back to earth at night and causes fading by varying the phase with the ground wave.

CLASSROOM PROBLEM

1. When reception is poor due to being near the edge of the skip zone, what change should be made in frequency?

   ANS:_____

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CHOICE OF FREQUENCY FOR COMMUNICATION

Low Frequencies
(200 - 400 KC)

Good at all times up to 50 miles except in severe static.

Good at night up to 200 - 300 mi., especially over water.

Not very useful in tropics due to static.

High Frequencies
(2 - 16 MC)

Distance	Night	Day
50 mi.	Use any frequency	Use any frequency
300 mi.	3 - 5 MC.	4 - 7 MC.
1000 mi.	5 - 7 MC.	6 - 10 MC.
3000 mi.	7 - 9 MC.	9 - 16 MC.

Ultra High Frequencies
(above 50 MC)

Good at all times up to 50 miles.

Good up to 75 mi. with aircraft at 3000 ft.

Good up to 150 mi. with aircraft at 10,000 ft.

The above chart indicates approximate results to be expected from low power equipment. During the winter, the best signals on high frequencies will generally be obtained below those frequencies shown. During the summer, the best signals on high frequencies will generally be obtained at higher frequencies than those shown.

The tropics can be considered as summer all year round.

Fadeouts may necessitate the use of low or ultra high frequencies.

EXAMPLE PROBLEMS

1. An aircraft desires to communicate with a station 300 miles away. What frequency would be expected to give best signals during a winter day? A summer day?

   ANS: Winter day 4 to 6 MC. Summer day 5 to 7 MC.

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2. An aircraft desires to communicate with a station 600 miles away. What frequency would be expected to give best signals during a winter day? A winter night?

   ANS. Winter day about 7 MC. Winter night about 5 MC.

CLASSROOM PROBLEMS

1. An aircraft in far northern latitudes desires to communicate with a station 200 miles away. There is a complete fadeout on high frequencies. On what frequency might communication be established at night? Is there much chance of establishing communication during daytime?

   ANS:_____

2. An aircraft in the tropics desires to communicate with a station 600 miles away. What frequency would be expected to give best signals during the day? At night?

   ANS:_____

3. An aircraft in the southern hemisphere, during July, desires to communicate with a station 1000 miles away. What frequency should be best during the day? At night?

   ANS:_____

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HOMEWORK

1. Static generally dies down after midnight. What causes this? When do thunderstorms in the tropics die down, in your estimation?

   ANS:_____

   _____

2. Static is generally much worse between sundown and midnight than at noon. Why?

   ANS:_____

3. If there is a complete fade-out on high frequencies, how would you attempt to maintain communication?

   ANS:_____

4. Why would you not expect to encounter fading on UHF signals?

   ANS:_____

5. During October, would an airplane flying in the northern hemisphere choose about the same frequency for communication over a given distance as one flying in the southern hemisphere? What if the plane was flying in the tropics?

   ANS:_____

6. An airplane is the northern hemisphere, during July, desires to communicate with a station 1,000 miles away. What frequency should be best during the day? At night?

   ANS:_____

   Would you expect a higher or a lower frequency to be required for long distance communications at noon than at sunset?

   ANS:_____

   A domestic airline uses a frequency of about 5 mc. for day communication. How far would you expect normal aircraft communication during the day in January? In April? In July? In October?

   ANS:_____

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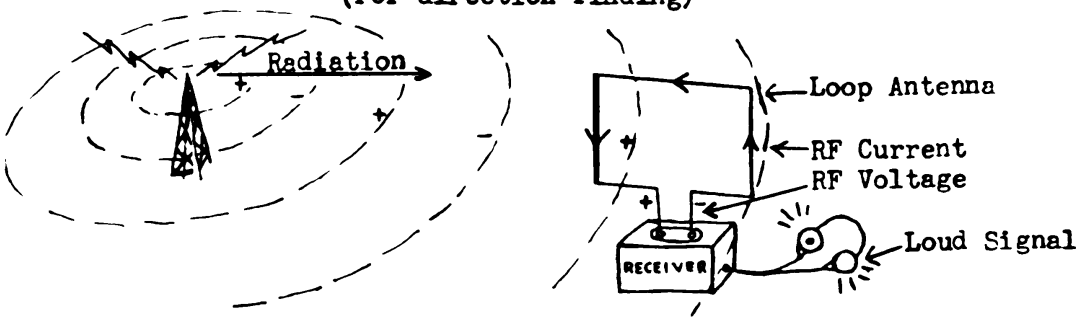
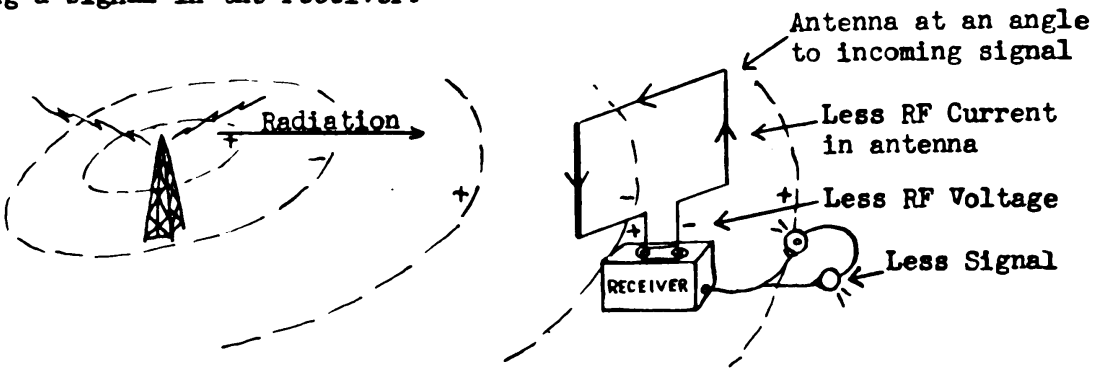
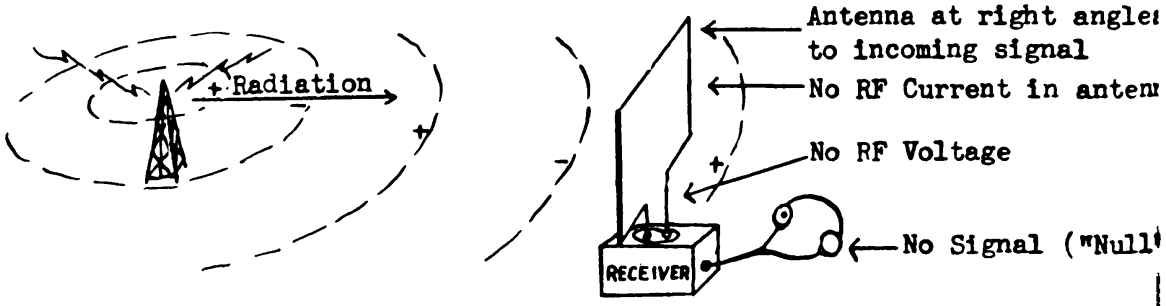
LOOP ANTENNAS
(For direction finding)



The loop is in line with the transmitting station. The loop is cutting the radiated field of the transmitter. Since this field is changing rapidly (at radio frequency), RF voltage is set up in the loop. Current flows through the loop, producing a signal in the receiver.



The loop is turned at an angle to the transmitting station. The loop now cuts the RF field at an angle. Less RF voltage is set up in the loop. A weaker RF current flows through the loop, producing a weaker signal in the receiver.



A loop is turned at right angles to the transmitting station. It does not cut the RF field. No RF voltage is set up in the loop. No RF current flows and there is no signal in the receiver.

As the loop is rotated further, the signal will increase until it becomes maximum when the loop is again in line with the station.

The loop is rotated to the point of least signal (or "null") for direction finding. Signal strength changes most rapidly with rotation near the null. Volume should be kept fairly high as the ear is most sensitive to signal changes at high levels.

With this type of loop, it is impossible to tell which face of the loop is pointed toward the station; i.e., whether the station is in front or back of the loop.

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FOR THE USE OF LOOP ANTENNAS IN DIRECTION FINDING, SEE "NAVIGATION PRINCIPLES".

EXAMPLE PROBLEMS

1. Will the loop pick up signals arriving from above it?

   ANS: Yes. For this reason, greatest accuracy is secured when the loop receives energy only via ground wave (horizontally).

2. The loops commonly used on aircraft are round instead of square. Do they operate in the same manner as square loops?

   ANS: Yes.

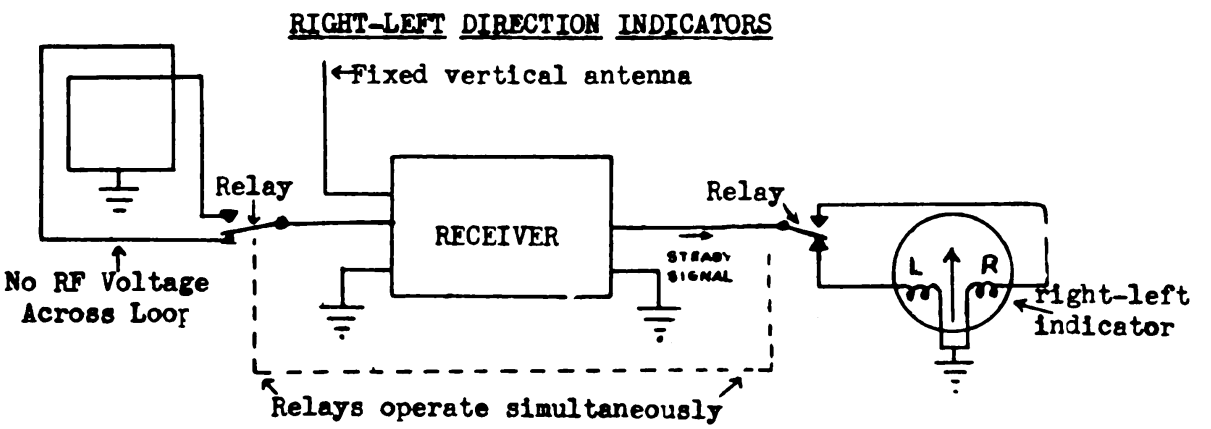
CLASSROOM PROBLEMS

1. Why does this type of loop operate more accurately on low frequency signals?

   ANS:_____

2. The amount of reflection from the ionosphere increases with frequency. The distance covered by the ground wave decreases with increased frequency. Which should produce the more accurate directional readings, low frequencies of 200 to 400 KC or broadcast frequencies of 550 to 1500 KC?

   ANS:_____



The loop antenna and the fixed vertical antenna ("sense" antenna) are both coupled to the receiver input. They are adjusted so each antenna supplies an equal RF voltage to the receiver when a signal is picked up by both.

The two relays operate simultaneously. One switches the receiver from one half of the loop to the other. The second relay switches the receiver output from one side of the indicator winding to the other.

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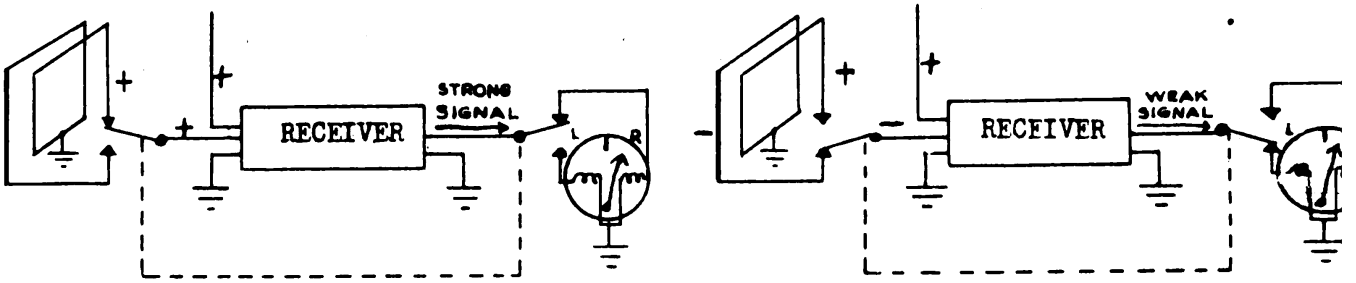
When the loop is at right angles to the transmitting station, it does not pick up any signal. The fixed antenna receives equally well from all directions, so it supplies a constant signal to the receiver. The indicator needle stays in the center of its scale, since the action of the relay causes the same voltage to be placed first on one winding, then on the other. The needle is heavy enough so it will not vibrate back and forth with equal energy on both coils.



The loop is turned so the station is to the right of the null.

When the relay is up, the RF voltage in the loop adds to the RF voltage from the fixed antenna. A strong signal is produced in the receiver. This exerts a strong right hand pull on the indicator needle.

When the relay is down, the RF voltage in the loop opposes the RF voltage from the fixed antenna. A weak signal is produced by the receiver. There is little force exerted to pull the indicator needle back to the left.

Since the relays operate rapidly, the average pull exerted causes the indicator needle to point to the right. This indicates automatically that the station is to the right of the loop null setting.

EXAMPLE PROBLEM

1. What type of relay is best adapted to the right-left direction indicator?

   ANS: The relays handle only small currents, but must operate rapidly and quietly. Mechanically operated relays are not as well adapted to this use as are vacuum tube relays. The common method is to use vacuum tubes, biased to cutoff. Relay action is then obtained by applying AC grid voltage to the proper frequency.

CLASSROOM PROBLEM

1. Describe the action of the above right-left direction indicator when the loop is turned so the station is to the left of the null.

   ANS:_____

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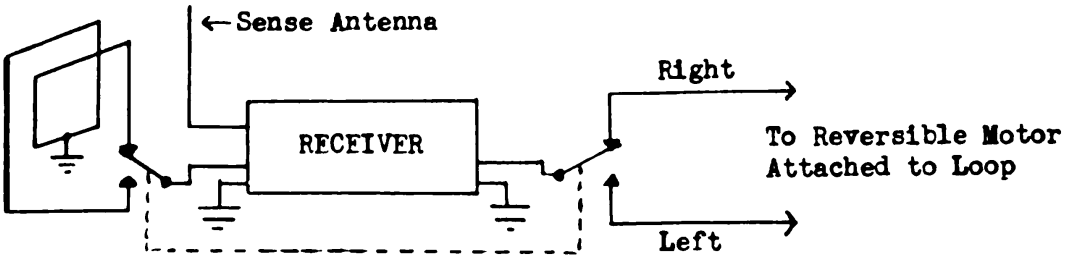
AUTOMATIC DIRECTION FINDERS



The operation of the automatic direction finder is similar to that of the right-left direction indicator. The "indicator" is no longer used. The contact points of the receiver output relay lead to a reversible motor which will rotate the loop.

When the station is to the right of the loop null, a pair of contacts is closed which start the motor, automatically rotating the loop null toward the station.

When the null reaches the direction of the station, the contacts open. This stops the motor and leaves the loop in the null position.

The loop is connected to a pointer on a 360 degree scale. This pointer automatically comes to rest pointing toward whatever station is tuned in on the receiver.

FOR THE USE OF AUTOMATIC DIRECTION FINDERS, SEE "NAVIGATION PRINCIPLES".

EXAMPLE PROBLEMS

1. What type of relay is best adapted to use in the automatic direction finder?

   ANS: The relay on the receiver input consists of two vacuum tubes having cutoff bias. Positive bias is applied first to one, then the other, thus closing first one loop connection, then the other.

   The relay on the receiver output must handle sufficient current to operate (drive) the loop motor. A pair of mercury vapor tubes are used here, with their grids biased to cutoff. They operate in the same manner as the tubes on the receiver input side.

2. The loop on an automatic direction finder rotates constantly. What is the probable cause?

   ANS: This can be caused by a failure of any one of the four tubes used as relays.

3. What is the result of failure of both the input relay tube and output relay tube which cause right hand rotation?

   ANS: The motor will no longer rotate the loop to the right. Any signal received from the left of the loop will cause rotation to the left, but signals from the right of the loop will not cause rotation.

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CLASSROOM PROBLEMS

1. What is the result of failure of both output tubes?

   ANS:_____

2. What is the effect on accuracy of indicated directions when tne fixed "sense " antenna is removed?

   ANS:_____

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RADIO PRINCIPLES

HOMEWORK

1. What is the effect on the operation of a right-left direction indicator if the sense antenna is removed from the receiver?

   ANS:_____

2. How many tubes are required to perform the function of the receiver input relay of the right-left direction indicator? Of the output relay?

   ANS:_____

3. What is the effect of failure of one of the input relay tubes on the operation of a right-left direction indicator?

   ANS:_____

4. In an automatic direction finder, what is the result of failure of both the input relay tube and output relay tube which cause left hand rotation?

   ANS:_____

5. In an automatic direction finder, why are mercury vapor tubes best adapted for use as output relay tubes?

   ANS:_____

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LOCATION OF RADIO EQUIPMENT TROUBLE

Many radio failures which occur can be corrected in flight. The following routine procedures should be carried out in order when endeavoring to locate and correct troubles encountered.

RECEIVER

Symptoms	Probable Troubles	Corrections
All receivers dead and dial lights out	Main fuse blown Power failure	Replace fuse Switch batteries
One receiver dead and dial light out	Individual fuse blown	Replace fuse
One receiver dead; dial light OK; dynamotor or vibrator not operating	Dynamotor fuse blown Defective dynamotor Defective vibrator	Replace fuse Inspect brushes Replace vibrator unit
One receiver dead; one tube not lighted	Filament burned out	Replace tube (or tubes)
One receiver dead; no visible symptoms	Audio switch in wrong position Defective tube Defective headphones	Switch headphones to receiver Replace tubes Try another set of headphones
One receiver dead after transmission	Transmitter relay stuck Defective tube	Check relay; clean contacts Replace tubes
Receiver alive, no signals heard	Antenna defective Band switch defective Defective tube	Check antenna Try another band Replace tubes
Receiver alive; weak signals	Defective tube Band switch defective Receiver on wrong band Radio fade-out	Replace tubes Try another band Try another band Listen for static (absent in fade-out); listen for own transmitter
Receiver alive; weak signals in icing	Antenna iced	Deice antenna if possible
Receiver normal but no beat oscillator	Defective BFO tube	Replace BFO tube
Receiver noisy with antenna connected	Antenna open or rubs Poor receiver case bonding Tachometer shaft makes noise Defective magneto shielding Defective spark plug shielding Generator noisy	Check antenna connections Check bonding of case Graphite shaft; check bonding Check and clean shielding Tighten or replace shielding Check brushes and shielding
Receiver noisy with antenna disconnected	Defective band switch Defective tube Noisy dynamotor	Try another band; clean switch Replace tubes Clean commutator with paper

IMPORTANT: A supply of spare fuses, vibrators and tubes should be carried at all times. Several filaments may be in series. If one fails, others will go out too. NEW PARTS ARE OFTEN DEFECTIVE. TEST THEM.

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RADIO PRINCIPLES

EXAMPLE PROBLEMS

. In testing fuses, is it sufficient to inspect glass cased fuses visually?

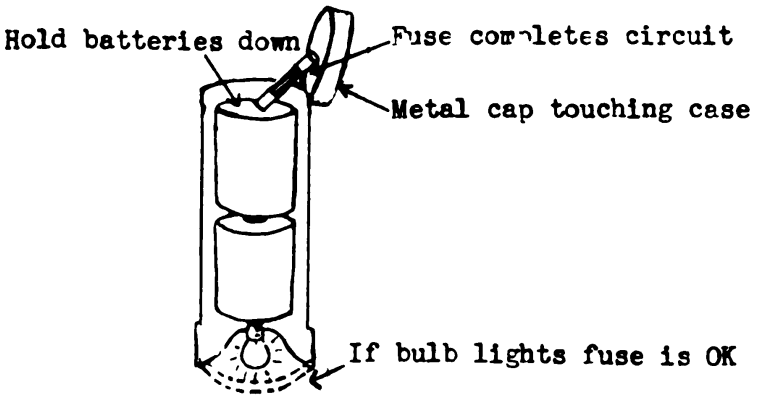
ANS: No. An open-circuit may not be visible. One way to test fuses is by the use of a flashlight.

Remove flashlight cap.

Hold flashlight downward, with switch on.

Use the fuse to complete the circuit between the cap and the end of the flashlight cell.

Flashlight bulb will light when fuse is good.



. What is meant by a receiver being "dead"?

ANS: No sound is audible in headphones attached to the receiver, even though the receiver is switched on.

. What is meant by a receiver being "alive" but no signals heard?

ANS: A "live" receiver causes a slight sound in the headphones when it is on. This clearly distinguishes it from a "dead" receiver.

CLASSROOM PROBLEMS

. What procedure would you follow if all radio equipment is operating normally except that one receiver is dead and its dial light and all tubes are lighted?

ANS:_____

_____

. The dial light on a receiver goes out. The receiver continues to operate normally. What has probably happened?

ANS:_____

. A receiver is noisy. Why would you first try disconnecting the antenna?

ANS:_____

. Why would you suspect a failure of the first RF amplifier tube if the receiver will not pick up signals after transmission but is not dead?

ANS:_____

. In an airplane, it is best to feel the vibration rather than depending on the ear to determine whether the vibrator or dynamotor is operating. Why?

ANS:_____

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CW TRANSMITTER

Symptom	Probable Trouble	Corrections
All radio equipment dead	Main fuse blown	Replace fuse
	Power failure	Switch batteries
Transmitter does not start; lights dim when trying to transmit	Battery switch off or on cart	Switch to battery
	Low battery	Switch batteries if possible
Dynamotor does not start	Dynamotor fuse blown	Replace fuse
	Defective dynamotor relay	Check relay; clean contacts
Tubes do not light	Filament fuse blown	Replace fuse
	Filament burned out*	Replace tubes
No plate or antenna current; no visible symptoms	High voltage fuse blown	Check high voltage fuse
	Defective tuning unit	Try another tuning unit
	Defective tube	Replace tubes
Plate current OK; antenna does not tune normally	Defective antenna	Check antenna; try another antenna
Plate current OK; antenna tuned; no antenna current	Probably none	Check antenna terminal for RF with wood pencil
Plate and antenna current OK; unable to contact any station	Poor conditions or fadeout	Check signals from other stations
	Tuned to wrong frequency	Check transmitter frequency
	Poor choice of frequency	Try another frequency

*Transmitter on aircraft having 24 volt electrical systems usually operate pairs of tube filaments in series. One filament out will prevent both tubes from lighting.

IMPORTANT: A supply of spare fuses and spare tubes should be carried at all times.

CAUTION

The voltage of the plate supply dynamotor is high enough to cause a fatal shock. Always be sure the dynamotor is stopped before touching a high voltage fuse or reaching inside the transmitter.

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RADIO PRINCIPLES

EXAMPLE PROBLEMS

1. The filaments of two RF tubes in a transmitter are connected in series. Is it necessary to replace both tubes if only one is burned out?

   ANS: No. If the burned out tube is replaced and operation is then normal, there is no necessity for replacing the other tube.

2. Why may operation be normal even though no antenna current is indicated?

   ANS: The resistance of the antenna may be so high that the antenna current is too small to operate the antenna ammeter. Touching a wood pencil to the antenna terminal will indicate immediately whether RF voltage is present.

3. Why is it important to be sure to use a wood pencil when testing the RF voltage?

   ANS: A severe burn will probably result if a metal pencil is used.

CLASSROOM PROBLEMS

1. Why will the lights dim when an attempt is made to start the transmitter with a low battery?

   ANS:_____

2. Why must you be sure the dynamotor is stopped before touching the high voltage fuse?

   ANS:_____

3. The plate milliammeter on usual aircraft transmitters indicates the total plate current drawn by all tubes. If no plate current is indicated when the key is closed, which is more likely to be defective- the oscillator or the RF amplifier tube?

   ANS:_____

4. Why might the use of too long an antenna on the frequency indicator cause the transmitter to be set on the wrong frequency?

   ANS:_____

5. Two tubes in a transmitter go out. Two new tubes are placed in the sockets. Neither lights. All connections and fuses are correct and neither socket is broken. What might be wrong?

   ANS:_____

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RADIOTELEPHONE TRANSMITTER

Symptom	Probable Troubles	Corrections
Improper RF operation	Same as for CW transmitter	Follow procedure for CW transmitter
Modulator tubes don't light*	Filament burned out Defective CW-voice switch	Replace tubes Check switch contacts
Speech amplifier tube does not light	Filament burned out	Replace tube
Total plate current does not increase when transmitter switched to voice or tone	Defective AF tubes Defective CW-voice switch Modulator bias too high	Replace AF tubes Check switch contacts Decrease bias
Antenna current does not increase with modulation	Improper coupling Audio gain too low	Decrease antenna coupling Increase audio gain
Antenna current decreases with modulation	Improper coupling	Decrease antenna coupling
Antenna current increases more than 22% with modulation	Improper coupling Audio gain too high	Increase antenna coupling Decrease audio gain
Normal on "tone"; no modulation on "voice"	Defective microphone jack Defective microphone	Check microphone jack Try another microphone

*Transmitters on aircraft having 24 volt electrical systems usually operate pairs of tube filaments in series. One filament out will prevent both tubes from lighting.

IMPORTANT: A supply of spare fuses and spare tubes should be carried at all times.

CAUTION

The voltage of the plate supply dynamotor is high enough to cause a fatal shock. Always be sure the dynamotor is stopped before touching a high voltage fuse or reaching inside the transmitter, modulator or power unit.

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RADIO PRINCIPLES

EXAMPLE PROBLEMS

1. Why must a transmitter be operating properly on CW before modulation is attempted?

   ANS: Transmission is impossible without RF output from the transmitter In addition, the RF section of the transmitter must be adjusted properly before modulation can take place.

2. In many combination CW-radiotelephone transmitters, tubes of the same type are used in the modulator as in the RF section of the transmitter. If short on spare tubes, is it possible to remove the tubes from the modulator and use them in the RF section? Is radiotelephone operation possible when this is done?

   ANS: In such a transmitter, the tubes may be moved in this way and operation continue on CW. Radiotelephone operation will be impossible, since there will then be no modulator tubes.

3. Tone modulation is generally obtained by operating the speech amplifier tube as an audio frequency oscillator. Will it be possible to use tone-modulated CW if the modulator tubes are removed?

   ANS: No. The modulator tubes are required to amplify the output of the speech amplifier tube to a sufficient value to modulate the CW output.

CLASSROOM PROBLEMS

1. The CW-voice switch usually has contacts to turn speech amplifier and modulator filaments on when switched to "voice". May dirty contacts prevent operation on "voice"?

   ANS:_____

2. Why is it necessary to decrease coupling if the antenna current does not increase when the transmitter is modulated? What else may be wrong?

   ANS:_____

3. Describe the procedure to be followed in case the transmitter operated normally on "tone" transmission but does not modulate on "voice".

   ANS:_____

4. A transmitter is modulated by two tubes in Class B. Disregarding dynamotor voltage variation, would you expect <u>total</u> plate current to change while the transmitter is being modulated? Why?

   ANS:_____

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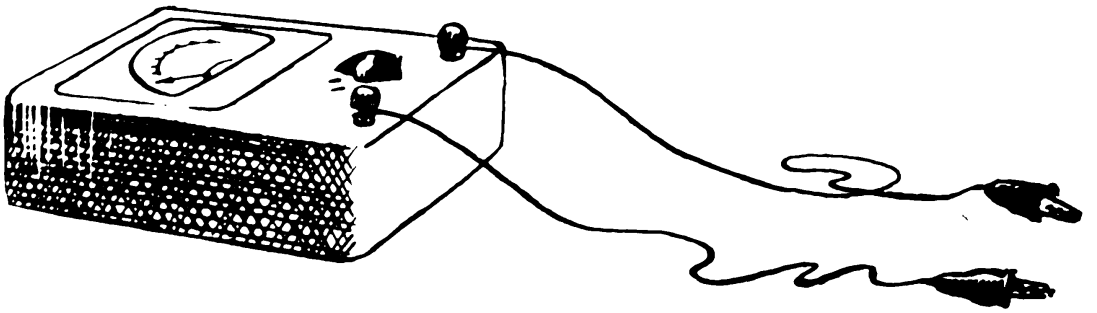
USE OF TEST INSTRUMENT
(Volt-ohmmeter)



The test instrument is used when the routine checks listed previously have failed to disclose the nature of the trouble encountered.

The test instrument is always used as a voltmeter when equipment is tested with power on. It is always used as an ohmmeter when equipment is tested with power off.

TESTING WITH POWER ON

The test instrument is used as a voltmeter to test the voltages in various parts of the circuit. These can be compared with the normal voltages and will often indicate the nature of the trouble. Voltages in some circuits may be indicated too low because of relatively low resistance of the voltmeter and high circuit resistance.

TESTING WITH POWER OFF

The test instrument is always used as an ohmmeter when testing with power off.

The resistances of the various resistors are checked and compared with the rated values. During this process, care should be taken to be sure no other resistances are in parallel with the particular one being checked. If so, allow for the other resistors.

Condensers are checked for short-circuits (zero resistance). In some cases, there may be resistors in parallel with the condensers, causing a false indication. A condenser checked alone should show an open circuit. However, electrolytic condensers may show some resistance and still be normal.

EXAMPLE PROBLEM

1. Why should a test instrument never be used as an ohmmeter when testing equipment with the power on?

   ANS: The ohmmeter is set for full scale reading with the small dry battery in the instrument. Additional voltage will burn out the meter.

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CLASSROOM PROBLEM

1. Why will no readings be obtained if the test instrument is used as a voltmeter when testing equipment with the power off?

ANS:_____

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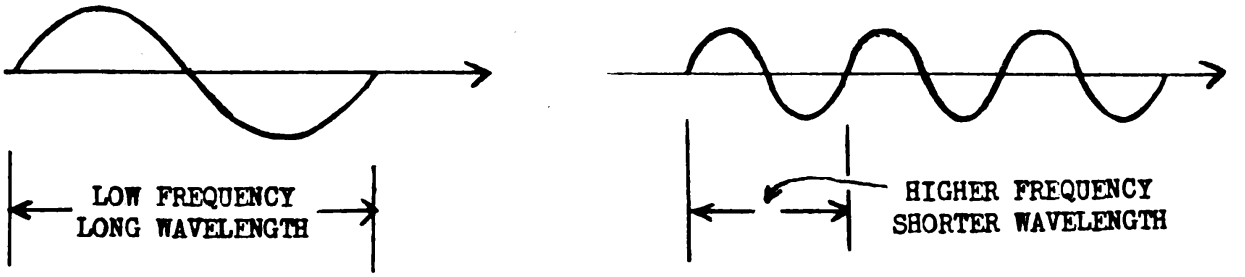
RELATION OF FREQUENCY TO WAVELENGTH



Radio waves travel through air at a speed of 186,000 miles per second or 300,000 kilometers per second.

The length of a radio wave is:

$$\text{Meters} = \frac{300{,}000}{\text{Kilocycles}}$$

Frequency can be found by:

$$\text{Kilocycles} = \frac{300{,}000}{\text{Meters}}$$

Values may be found by the above formulas or in the table below.

KC or m	m or KC	KC or m	m or KC
10	30,000	100	3,000
20	15,000	150	2,000
30	10,000	200	1,500
40	7,500	300	1,000
50	6,000	400	750
60	5,000	500	600
80	3,750	600	500

The frequency under consideration is often stated roughly in wavelength. A high frequency broadcast station might be said to operate in the "19 meter" band. This would refer to a frequency in a band in the neighborhood of 16,000 KC.

Similarly, "short wave" transmission is the same as "high frequency" transmission.

Wavelength is also used as a convenient means of speaking of antenna length or the spacing between two different sections of an antenna for a given frequency.

EXAMPLE PROBLEMS

1. From the table, what wavelength corresponds to a frequency of 10 KC?

   ANS: 30,000 meters

2. From the table, what frequency corresponds to a wavelength of 10 meters?

   ANS: 30,000 KC.

CLASSROOM PROBLEM

1. Convert the following:

   5000 KC = _____meters 50 mc = _____meters

   50 meters = _____mc 250 meters = _____KC

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HOMEWORK

1. The first RF tube of a receiver is usually protected from high RF voltage by a resistor connected between antenna and ground. On completing a transmission, you find the receiver is alive, but no signals are heard. Which tube would you suspect may have failed during transmission? What would cause such a failure?

   ANS:_____

2. Would you test a spare fuse before inserting it in the equipment? Why?

   ANS:_____

3. Why will the transmitter fail to operate if the electrical system of a plane in flight is switched to "battery cart" position? Why will the receivers operate normally in this position?

   ANS:_____

4. What meter on a transmitter will indicate that the transmitter is loaded even though the antenna ammeter shows little or no current?

   ANS:_____

5. The speech amplifier tube is often used as an audio frequency oscillator to produce a tone in the headphones while keying a CW transmitter. Would failure to hear this "side tone" necessarily indicate that there was no CW output?

   ANS:_____

6. Refer to Question 5. If the side tone is heard when keying, does it necessarily indicate that the transmitter is operating properly on CW?

   ANS:_____

7. Why should you resort to the use of a test instrument only after trying all possible means of checking the equipment while it is still intact and connected?

   ANS:_____

8. Why is it generally poor policy, while in flight, to cut wires leading to soldered connections?

   ANS:_____

9. Would you use the trailing wire or the overhead antenna for transmission during the time the plane was being gassed?

   ANS:_____

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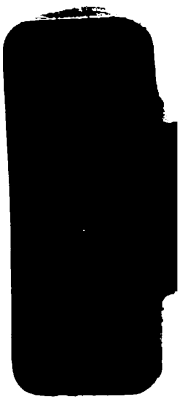

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